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Changing the Paradigm of Drawing Consumption

Master’s Thesis

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ABSTRACT OF THE MASTER'S THESIS

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Drawings have existed from the early times of mankind as a means of communicating thoughts forward, crystallizing ideas or simply for the sake of remembering something. While the production and delivery methods of drawings in the construction industry may have improved over the years, especially during the past few decades, the way to consume drawings has not progressed correspondingly.

This research seeks to provide a comprehensive overview on the possibilities that may emerge from improvements in the process of drawing consumption, as well as to function as a guideline for anyone trying to understand the consumption of drawings as a practice, and furthermore, for anyone who may be interested in developing new technologies that specifically improve the consumption process of drawings. Findings of the study could potentially be used as a reference when developing new technologies, or at minimum they will contribute to the body of knowledge on the process of drawing consumption and on the philosophical qualities of drawings – which are topics that have not been studied extensively.

As the title of the thesis suggests, an underlying hypothesis of the study is that a paradigm shift in the field of drawing consumption is something that – if attained – would allow the industry to transcend their current practices by improving the industry holistically. The research consists of two parts: a theoretical study during which the qualities and practices of drawing consumption are studied thoroughly, and a proof-of-concept study, that is an attempt to introduce a new technology in a form of a prototype that could work as a guideline or a contribution for any party interested in further research or development regarding the subject.

Keywords Drawing Consumption, BIM, Prototype, Paradigm Shift

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Tämän tutkimuksen pyrkimyksenä on tarjota kokonaisvaltainen kuva mahdollisuuksista joita voi seurata parannuksista piirustusten kulutusprosessissa, sekä toimia opasteena niille tahoille jotka haluavat ymmärtää piirustusten kulutusta prosessina – ja edelleen keille tahansa jotka ovat kiinnostuneita kehittämään uusia teknologioita spesifisti piirustusten kulutusprosessin parantamiseksi. Tutkimuksen löydöksiä voidaan hyödyntää referenssinä uusia teknologioita kehittäessä, tai vähintäänkin ne palvelevat kasvattamalla sekä teoreettista ymmärrystä piirustusten kulutusprosessiin liittyen että piirustusten filosofisiin ominaisuuksiin liittyen. Kyseessä ovat aiheet joista ei löydy kattavaa tutkimustietoa ennestään.

Kuten työn otsikko antaa ymmärtää, tutkimuksen perimmäisenä hypoteesina on olettamus siitä että paradigmamuutos piirustusten kulutusprosessiin liittyen auttaisi rakennusalaa pääsemään uudelle tasolle toimintatavoissaan edesauttaen alaa kokonaisvaltaisesti. Tutkimus koostuu kahdesta osa-alueesta: Ensimmäinen osa on teoreettinen tutkimus, jonka aikana piirustusten ominaisuuksia ja prosesseja tutkitaan perusteellisesti. Toinen osa on käytännön tutkimus, jossa esitellään uusi teknologia prototyypin muodossa, joka voi toimia opasteena tai kontribuutiona kenelle tahansa osapuolelle, joka on kiinnostunut aiheeseen liittyvästä tutkimuksesta tai tuotekehityksestä.

Asiasanat Piirustusten kulutus, BIM, Prototyyppi, Paradigmamuutos

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Thanks to ___________ for helping with _________ and of course with ________.

Leevi Valkoniemi, Espoo, 30.9.2019

TABLE OF CONTENTS

1 Introduction 1
1.1 Background 1
1.2 Purpose of the Study 2
1.2.1 Theoretical Research 2
1.2.2 Practical Research (Proof-of-concept) 3
2 Literature Review and the Key Concepts 4
2.1 Paradigm and paradigm shift 4
2.2 Theoretical Findings for Research Questions 5
2.2.1 Research Question I 5
2.2.2 Research Question II 9
2.2.3 Research Question III 14
2.2.4 Research Question IV 19
3 Proof-of-concept Study 24
3.1 First Round of Interviews 24
3.1.1 Interview Setting – First round 24
3.1.2 Interview Questions – First Round 25
3.1.3 Data Analysis – First Round 26
3.1.4 Interview Findings – First Round 27
3.2 Prototype 30
3.2.1 Prototype Content 30
3.3 Second Round of Interviews 40
3.3.1 Interview Setting – Second Round 40
3.3.2 Interview Questions – Second Round 40
3.3.3 Data Analysis – Second Round 41
3.3.4 Interview Findings – Second Round 42
3.4 Final Analysis of the Prototype 43
3.4.1 Summary of the Next Steps of the Technology 44
3.4.2 Quality Function Deployment Analysis 48
4 Discussion 53
4.1 Evaluation of the Study 57
4.2 Future Research and Development 58
5 References 59
Appendix I i
Appendix II iv

Appendix III...v
Appendix IV...vi

1 INTRODUCTION

1.1 BACKGROUND

Drawings have existed from the early times of mankind as a means of communicating thoughts forward, crystallizing ideas or simply for the sake of remembering something. They have also been used for technical purposes for centuries, of which a fair testament would be the works of Leonardo Da Vinci (1452-1519). [1] Regardless of the lengthy history of drawing as a practice, and its application into the sciences even before Leonardo Da Vinci, it was not until the seventeenth century and later when western mathematicians and geometricians, such as Girard Desargues (1591-1661), Andrea Pozzo (1642-1709), Brook Taylor (1685-1731), and Johann Heinrich Lambert (1728-1777), developed their breakthroughs in the fields of projection and perspective drawings. [2] The outlook of drawings have remained essentially the same for hundreds of years. Figure 1 is a picture of an authentic drawing of Eiffel Tower structures from the 19th century, which seems to be very similar to drawings made today. While the production and delivery methods of drawings may have improved over the years, especially during the past few decades, the way to consume drawings has not progressed correspondingly.

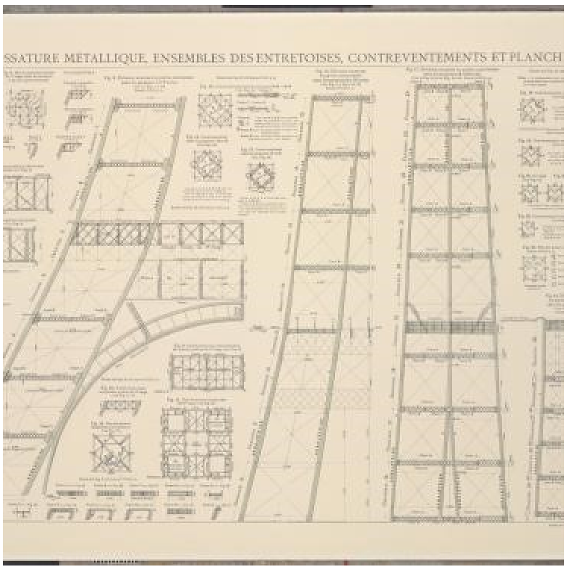

Figure 1: Picture of an original drawing of Eiffel tower structures. [3]

Most of the drawings today are made with BIM (Building Information Modeling) and/or CAD (Computer Aided Design) software, of which a vast number is still represented in 2D, despite the fact that an ever-growing number of projects are already modelled in 3D. [4] According to Kanungo et al. [5], 2D has been used mainly because of the physical restrictions of paper format. While paintings and drawings depicting three-dimensional-looking illustrations have been around for a very long time, the accuracy required in engineering drawings has inherently created the need to represent engineering drawings in a two-dimensional planar manner. [5]

1.2 PURPOSE OF THE STUDY

This research seeks to provide a comprehensive overview on the possibilities that may emerge from improvements in the process of drawing consumption, as well as to function as a guideline for anyone trying to understand the consumption of drawings as a practice, and furthermore, for anyone who may be interested in developing new technologies that specifically improve the consumption process of drawings. Findings of the study could potentially be used as a reference when developing new technologies, or at minimum they will contribute to the body of knowledge on the process of drawing consumption and on the philosophical qualities of drawings – which are topics that have not been studied extensively.

1.2.1 Theoretical Research

This study consists of two main targets. The first target is to understand what drawing consumption means in theory. Regardless of the rapid evolvement provided by technology in other stages of the lifespan of engineering drawings, the consumption side has not transformed in a corresponding manner. There is a lot of discussion about the future ways of consuming drawings, but little – if any – available studies that lay out the foundation of engineering drawings as a phenomenon. The second target is to conduct a proof-of-concept study for creating and testing the validity of a prototype created for the purposes of this research. The literal part of the study will be guided by four research questions. The first question is an attempt to get an overview of the possibilities that emerge through technology, and if some solutions that already exist can function as a groundwork to mitigate the probability of overlapping – or better yet – inferior innovations.

> *"Where is the industry at the moment regarding engineering drawings, and what – if any – are the most promising ideas emerging from the research that may provide new means to challenge the current paradigm of drawing consumption?"*

To understand how the process of drawing consumption would have to be broken down, and to test the hypothesis that the drawing consumption can be partly accounted for the notion that a better technology is simply yet to be emerged, the second question of the research tries to shed light onto the underlying forces, as well as the requirements and the needs that are manifested in the types of engineering drawings that we have been consuming for centuries.

> *"What are the underlying forces, the needs and the requirements that are manifested in engineering drawings universally?"*

The third research question is an attempt to discover and bring forth implicitly agreed upon ways of consuming drawings, as well as hidden potential that may abide in engineering drawings. Furthermore, this research question is a pursuit of articulating what would be worth a professional's while to get them to adopt new technologies.

> *"What are the ways in which engineering drawings are or can be used – besides the explicit ways – that can provide additional value to anyone or anything involved in the process of consuming drawings?"*

To offer some foundation to a possible prototype, the fourth research question will try to bring about an understanding of what is it that would have to be taken into account on a theoretical level, to be able to diffuse a new technology into the population of drawing consumers.

> *"What are the critical elements – both, positive and negative – that constitute a successful diffusion process of a new technology?"*

While these research questions are mainly theoretical, and the answers will first and foremost accumulate the body of knowledge on the philosophical issue at hand, all of the questions – to some extent – will function as a foundation for the second part of this research, which is an attempt to introduce the ideas to practice in a form of a proof-of-concept study.

1.2.2 Practical Research (Proof-of-concept)

To answer the challenge put forward by the title of this thesis (*Changing the Paradigm of Drawing Consumption)*, and to further draw conclusions to validate and reinforce the findings of the theoretical part of the research, the practical part of the research was conducted as a proof-of-concept study. The concept tested was a prototype of a technology created just for the purposes of this study. The prototype was based on the literature findings, as well as interview findings, that were then condensed into a suggestion of a possible future technology that could initiate a paradigm shift by the very nature of its properties. The technology was then used to conduct a second round of interviews, after which the results were analyzed to test the concept, and to draw further conclusions to enrich the findings of the theoretical part of the research.

While the theoretical foundation provided by the literature review can be utilized as a self-serving body of knowledge, and the proof-of-concept study can be analyzed in separation from the theoretical foundation, both of the sections affected one another in the making of this research.

2 Literature Review and the Key Concepts

The literature review consisted of four research questions unified together by a statement presented in the title of the thesis. While the title of a thesis may in many cases be a draft in the beginning, in the case of this particular research, the title "*Changing the Paradigm of Drawing Consumption*" carried along significant meaning, functioning as a unifying force between the research questions. Thus, the title of thesis could have been – and to some degree was – condensed into an additional implicit research question of *"what is the paradigm of drawing consumption, and how the field would have to go about changing it, if a paradigm shift was a desired outcome?"*

2.1 Paradigm and paradigm shift

The title of the thesis – changing the paradigm of drawing consumption – is predicated on a presupposition, that drawing consumption in the field of construction is a paradigm or has a paradigmatic element to it, and that there would be some value in shifting the presupposed paradigm. Whether the process of drawing consumption can be considered paradigmatic or not, makes a big difference in how one is to view possible new ideas or technologies that may provide means to attain a paradigm shift. As Thomas Kuhn states [6], "the decision to reject one paradigm, is always simultaneously the decision to accept another, and the judgment leading to that decision involves the comparison of both paradigms with nature and with each other". With this in mind, it is technically impossible to achieve a paradigm shift without first articulating the current paradigm.

Paradigms, according to Kuhn [6], are "universally recognized scientific achievements that, for a time, provide model problems and solutions to a community of practitioners". Kuhn [6] divides scientific problems into three main classes, though there can be more than that, which are: *determination of significant fact*, *matching of facts with theory*, and *articulation of theory*. To answer the implicit research question found in the title of this thesis, we are focusing on the third category of *articulation of theory,* as we are trying to articulate the underlying processes of drawing consumption that have been exercised for centuries, but have not been articulated by researchers. As Kuhn [6] states, paradigms provide model problems to a community of practitioners, which means the problems are arbitrary in the sense that the properties of a new paradigm cannot be predicted. Thus, trying to change the current paradigm of drawing consumption does not mean that the same problem ought to be solved, and in fact, changing the solution to an existing problem cannot be considered a paradigm shift, but simply another solution. A paradigm shift is thus a universally accepted change in the arbitrarily chosen problem and the solution of it.

If we consider the diffusion framework of Rogers [7], it does make, however, a lot of sense to address the problems that the current paradigm solves and take them into account when developing new technologies that could aid shifting the paradigm. Rogers [7] points out that a successful diffusion requires – among others – compatibility (i.e., the degree to which the new idea is perceived to be aligned with past experiences and existing values) and relative advantage (i.e., the degree to which the new idea is perceived as being better than the idea it supersedes). Thus, the technology attempting to bring about paradigm shift should – to some extent – be concerned with the problems the old paradigm has addressed and solved, bearing in mind, nevertheless, that the five perceived attributes suggested by Rogers [7] – which are compatibility, relative advantage, complexity, trialability and observability – could potentially help bringing about a paradigm shift.

2.2 THEORETICAL FINDINGS FOR RESEARCH QUESTIONS

The four research questions – that were introduced in the introductory chapter of this thesis – were the starting point of the research. Before being able to advance to the proof-of-concept study, the research questions provided a vast enough scope of research to gain an understanding of what needs to be understood of the field in general. Kuhn [6] suggests, that philosophical analysis, such as the search for assumptions within the old tradition, can be a good device for unlocking the riddles of a scientific field. With this in mind, the theoretical part of the research is to great extent – but not solely – an attempt to understand how drawings are consumed today.

2.2.1 Research Question I

The first question is an attempt to get an overview of the possibilities that emerge through technology, and if some solutions that already exist can function as a groundwork to mitigate the probability of overlapping – or better yet – inferior innovations.

> *"Where is the industry at the moment regarding engineering drawings, and what – if any – are the most promising ideas emerging from the research that may provide new means to challenge the current paradigm of drawing consumption?"*

It is important to mention, that as we speak of the consumption of engineering drawings and the new means to challenge the current paradigm of drawing consumption, we do not know what the new means are. Thus, we cannot simply compare the existing way of drawing consumption to the hypothetically better ways of drawing consumption. Thus, in our study, we need to look at the technological innovations that may bring about long-awaited changes in drawing consumption. Different future reports of construction industry focus on different technologies that will be important in the future. As drawing consumption is only a sub-activity under construction industry, there are no studies on the future possibilities of drawing consumption per se, which forces us to simply pick up the most likely technological innovations, phenomena, or ideas, that may challenge the paradigm of drawing consumption in the future. Based on future reports on construction industry and other sources estimating future goals for the industry [8–13], I identified the most likely candidates that will specifically affect the process of drawing consumption in the future. The following topics are trends or technologies that need to be considered when analyzing the future of drawing consumption, and will be discussed briefly in following chapters: *Mixed Reality & Virtual Reality* [8], *Drawingless & Paperless Engineering* [10], *Internet of Things & Industrial Internet* [11], *Artificial Intelligence & Machine Learning* [9], *Cloud Computing* [12], *Big Data* [13], and *Building Information Modeling* [12].

2.2.1.1 Mixed reality & Virtual Reality

Mixed reality, augmented reality, augmented virtuality and virtual reality are some of the most prominent solution for replacing or reinforcing traditional engineering drawings. Mixed reality, as explained by Chalhoub & Ayer [14], is a spectrum between reality and virtual reality. Reality being a state with no additional virtuality, while virtual reality being a state with no interaction with reality. Augmented reality and augmented virtuality are states of mixed reality, former having virtual objects added into reality, while the latter being a converse case of augmented reality in the virtuality continuum, as explained by Milgram & Kishino. [15] Virtuality continuum refers to the spectrum between the extrema of completely real environment and completely virtual environment, as depicted in Figure 2. In this study, we will use the term mixed reality to describe anything between reality and virtual reality.

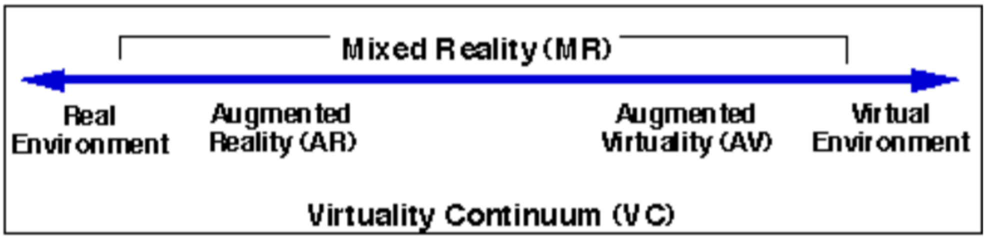

Figure 2: Virtuality Continuum as described by Milgram & Kishino. 15

Many companies have already developed solutions for bringing mixed reality into the process of utilizing model information. [16–19] The solutions developed by companies, such as Trimble or Autodesk, can be considered platforms, where information can be experienced in and extracted from. These are great technologies, and they enrichen the way we consume drawings, as there is less room for interpretational errors. These are not, however, developed specifically to improve drawing consumption, but model viewing generally.

2.2.1.2 Drawingless & Paperless Engineering

Discussion about drawingless engineering has emerged from the industry, but it is not clear what is meant by drawingless engineering. Drawingless engineering, of course, refers to the fact that traditional paper drawings are not used as the formal documentation to transmit information between parties [10], but the term does not suggest what the alternative to traditional drawings would be. Thus, drawingless engineering as such is not an adequate target, though it can be an outcome of a properly set up model-based environment. According to Herron [20], a model-based environment refers to an environment where the 3D model is used as the source for different processes of the project, such as design, analysis, documentation, manufacturing and so on. Paperless drawing, then again, simply refers to the fact that paper is not used, but it may well still mean that drawings are – in terms of information – at the same stage as if they were printed on paper. [20,21]

2.2.1.3 Internet of Things & Industrial Internet

Internet of Things (IoT) refers to the linking of physical objects onto each other, allowing them to communicate and to be controlled via wireless internet connection. [22] The things connected to the internet can be networks of sensors, actuators, processors, and computers, to mention but a few. [23] According to Laplante & Laplante [23], an IoT has great potential, for it enables precise tracking, servicing, analyzation and many other functions or means of communication that were formerly impossible for the objects in question.

Industrial internet is another term that is closely related to the internet of things. Basically, industrial internet refers to the whole ecosystem of processes, functions and equipment that are connected to industrial things – such as machinery, services, or functions – making them connected to the internet and capable of allowing communication between all the necessary parties [24]. As the term appears vague, Mäntylä [25] introduces the three categories that the industrial internet can be divided into. Industrial internet for operational benefits, for new customer value, and for digital business. The typical applications vary between these three clusters, but they all share the intelligence aspect of industrial internet.

From the definitions of these two terms, the internet of things and the industrial internet, we can conclude that the industrial internet often contains internet of things within its ecosystem. Internet of things is applied to industrial processes, machinery, et cetera, to create industrial internet. On the flipside, internet of things can refer to anything from consumer electronics' internet to industrial machinery's internet, thus making the term a common concept within the industrial internet. According to Rahkonen [22], digitalization and internet of things in construction industry is still at an early phase, but due to the fast advancements of the said technologies, new modes of operations and business models can be expected to emerge.

2.2.1.4 Artificial Intelligence & Machine Learning

Artificial intelligence (AI) refers to machinery that can perform tasks that are characteristic of human intelligence. By tasks, we can talk about things such as understanding a language, learning new things, seeing objects, et cetera. Artificial intelligence possessing all of the characters of human intelligence would be referred to as general artificial intelligence, while one possessing only some aspects of human intelligence would be referred to as narrow artificial intelligence. Machine learning would be one way of achieving artificial intelligence, while it can also be achieved by coding a set of explicit rules without utilizing machine learning. Machine learning is the ability of the machine to learn things through an algorithm that allows its own further adjustments in order to reach the given learning target. [26]

2.2.1.5 Cloud Computing

Cloud computing is the delivery of cloud based computing solutions or services to consumers over the internet. Cloud refers to the accessibility to these services from any location, while the services are actually located in different facilities all around the world. The provided services can be servers, databases, storages, software, and so on. Microsoft Incorporation [27] lists some apparent benefits of cloud computing, that are: cost, speed, global scale, productivity, performance, and reliability. Most of the cloud computing services can be categorized under three different groups, which are: infrastructure as a service, platform as a service, and software as a service. [27,28]

2.2.1.6 Big Data

Defining big data with a dictionary answer is not easy, as the boundaries of the term do not seem to be clear always. Big data can be described, however, through its common qualities, such as volume, velocity, and variety. It is massive amounts of data that need cost-effective and innovative ways to deploy it to useful form. It can be stored, transferred, traded, and analyzed, to mention but a few. Big data, in fact, is no different from data, besides it is so vast in amount, that understanding, handling, or analyzing big data requires much more sophisticated approach than with small sets of data. It can be also seen as a capital asset of a company, for it can create unprecedented value to a company when applied to practice properly. [29,30]

Digital data has some unique characteristics. Firstly, digital data is non-rivalrous. It can be used concurrently for many purposes, such as algorithms and applications. It is an asset that does not get consumed in a similar manner as a regular tangible good would. [30] Secondly, data is non-fungible. If one compares data to tangible goods, let us say gold bars, it can be quickly seen that a gold bar can be replaced by another gold bar, whereas a piece of data cannot be replaced by another piece of data, as they all carry different information. [31] Thirdly, MIT Technology Review Custom & Oracle [31] argues that data is an experience good, for it can only be attained if one knows the information itself. Leiponen [30], however, further argues that data is not necessarily an experience good, if it contains proper metadata.

2.2.1.7 Building Information Model (BIM)

Building information model, or BIM, is often regarded as a virtual 3D model of the construction project that contains relevant information of the project that can be used to estimate things like structural performance, energy consumption, costs, schedule, to mention but a few. [32] While it may be tempting to categorize BIM as fundamentally a better technology, it is more appropriate to consider BIM as a process change, as the change BIM brings is more than a mere software update: diffusing BIM into a project brings more inclusivity to all project parties, encourages sharing data or responsibility between the parties, and, for instance, changes the way that the building is maintained after the construction phase. [4,32]

2.2.1.8 Research Question I – Conclusions

When formatting this research question, I assumed that it would be possible to find some documentation on possible research on the future technologies regarding drawing consumption specifically. This turned out to be more difficult as initially expected, so I picked up the most prominent technologies or ideas that are universally agreed upon as technologies carving the future and appear to be suitable for the topic at hand, and as such, are possible accelerators of a paradigm shift in the field. The selected technologies or concepts are: Mixed Reality & Virtual Reality [8], Drawingless & Paperless Engineering [10], Internet of Things & Industrial Internet [11], Artificial Intelligence & Machine Learning [9], Cloud Computing [12], Big Data [13], and Building Information Modeling [12]. According to Kuhn [6], paradigms in sciences are very limited in their scope and precision when they are first introduced, so in the beginning they are mostly just a promise of success by providing results that seem interesting, rather than providing a full solution to a problem at hand. With this in mind, we can assume that the paradigm shift could be provided by some of these formerly introduced technologies or concepts, despite being limited in their scope and only offering a glimpse of promise at the moment.

2.2.2 Research Question II

To understand how the process of drawing consumption would have to be broken down, and to test the hypothesis that the drawing consumption can be partly accounted for the notion that a better technology is simply yet to be emerged, the second question of the research tries to shed light onto the underlying forces, as well as the requirements and the needs that are manifested in the types of engineering drawings that we have been consuming for centuries.

> *"What are the underlying forces, the needs and the requirements that are manifested in engineering drawings universally?"*

2.2.2.1 Consumers, Drawings and the Boundaries of Responsibility

According to Kazaz et al. [33], design plays an important role in the constructability of a project, and as drawings are the main document to show how buildings are built, drawings play a key role in constructability of projects. Constructability, according to The Institution of Professional Engineers New Zealand [34], "is a project management technique for reviewing construction processes from start to finish during the pre-construction phase. It will identify obstacles before a project is actually built to reduce or prevent error, delays and cost overruns". Thus, as Kazaz et al. [33] point out, design data, such as drawing data, should not be difficult to understand and to interpret, or the project will face issues with constructability. Similar point is made by French [35], as he points out that compared to artistic drawings, where the drawer can leave more things open for interpretation, engineering drawings have to minimize the room for interpretation to mitigate risks. Another important difference French [35] discusses is that artistic drawings can be read by anyone, but the person reading engineering drawings has to be educated. Thus, we can suggest that in contrast to artistic drawings, engineering drawings share the responsibility of the transmission of the correct message not only to the drawer, but also to the consumer of the drawing. This is an important point when changing the paradigm of drawing consumption, as the consumer of the drawing has as much as legal liability to interpret drawings correctly, so the clarity and universal rules of drawings play a big role in drawing consumption.

Herron [20] points out that 2D representations of objects rely on human capability to interpret and understand the object in 3D space, which is – to some extent – error-prone and time consuming. Firstly, one needs to represent a 3D object in 2D, so that someone else can read the 2D and translate it into actuality in 3D. Herron [20] further lays out some apparent benefits of 3D models, which are: Data Associativity, Automation, Improved Data Exchange, Time Savings, Data Reuse, Value of Archived Data, and Reduced Non-Conformance Costs. While she is primarily talking about 3D models in general, I shall argue that all of these can also be directly linked to the benefits of digitalized drawing data in relation to traditional 2D drawings.

2.2.2.2 Drawing sheet

The main format of drawing consumption have been paper sheets for a very long time. While paper sheets have some obvious benefits, like cheap material costs and applicability to any situation (construction site or building authorities, to mention but a few) without high costs, it is, however, becoming an outdated medium in developed countries, and can become an outdated medium in developing countries at a quicker relative speed than in post-industrial countries. [36] Agrawal & Agrawal [37] introduce the common drawing sheet sizes, and while the standard sizes may vary between different countries and legislative areas, the main idea delivered is that the drawing sheet sizes are due to the nature of technical drawings bound to some commonly agreed upon minimum and maximum sizes. On one hand, drawings need to be readable so the sheet sizes should not be too small, while on the other hand, handling too big drawing sheets may be a challenge – especially on site. Thus, common practice is that technical drawings are subjected to some standardized sizes.

2.2.2.3 Basic Elements of Engineering Drawings

Agrawal & Agrawal [37] talk about the basic elements of engineering drawings, that serve at different points of the life-cycle of the drawing. Some things on drawings may be purely because they make storing and handling of the drawing easier, other things are necessary for the reader to create a clear picture of the object represented, and some things are due to technical or practical limitations. Figure 3 shows a typical layout of a drawing sheet.

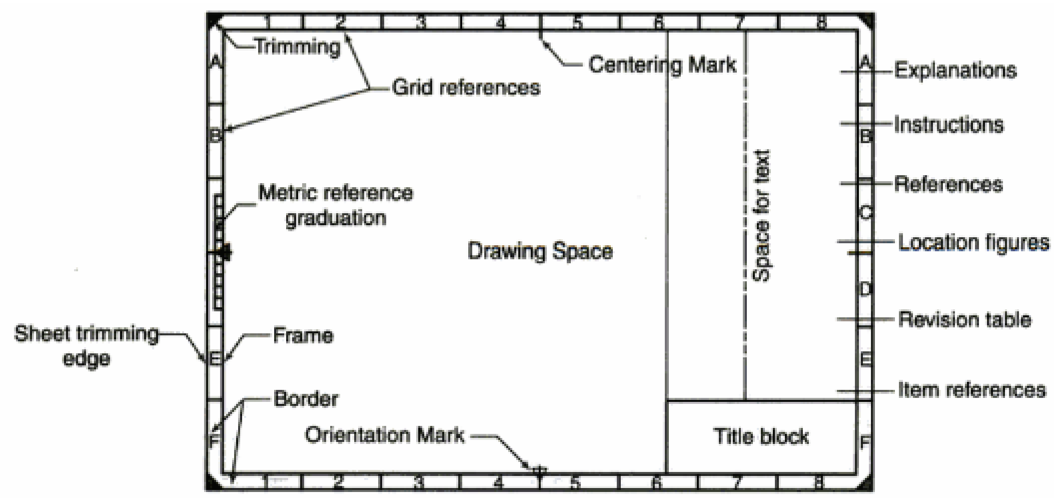

Figure 3: Typical Layout of Drawing Sheet. [37]

Agrawal & Agrawal [37] explain the usage for different common practices of drawing layout creation. Title block contains information, such as, who is the designer, what is represented in the drawing, where is the project located, what is the ratio of the drawing, et cetera. This is all necessary, as the drawings may be delivered separately to different consumers of the drawings, and some of the information may be absolutely vital to some actors during the life-cycle of the drawing. Space for text is reserved for similar purposes, but it often contains more variable information depending on the object or area that is being represented on the drawing. All of the textual information, nevertheless, are important to some consumers of the drawing, while to others they may not serve any purpose at all. Borders, frames, trimmings, and centering mark are for the purposes of placing information and printing the drawing, cutting it into shape and assisting with proper folding and storing of the drawing. Metric reference graduation is for the drawer and the consumer for reference. Drawing space is reserved for the actual objects and their dimensions, markings, and other annotations. [37]

Other actors that affect how a drawing should be interpreted are line types. While the line types and their meaning can differ among countries or standards, it is common that different line types convey different meaning. While continuous lines usually, if not always, refer to visible edges of the drawing object, dashed lines often refer to objects that are hidden behind the observed view. Also, dimension lines and any other annotations on drawings convey forward meaning that is not transmitted to the consumer otherwise. This kind of information has to be clearly presented. Figure 4 depicts different kinds of annotation objects. [37]

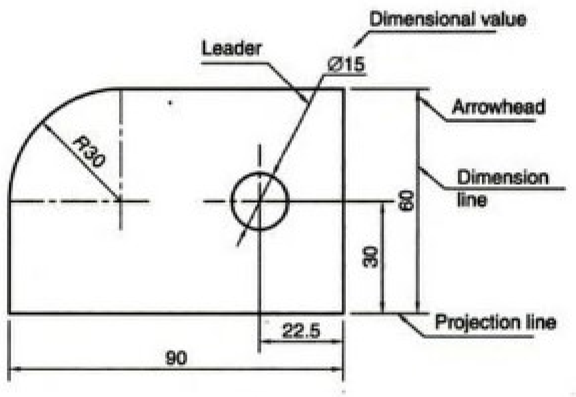

Figure 4: Drawing Annotations. [37]

Complex objects may contain multiple hidden lines behind the visible surface, thus making it mandatory to increase the amount of views by adding, for instance, section views. Section view is a view where the object is cut with an imaginary cutting plane, to present what is underneath the cutting plane and to clarify the shape of the object from the given perspective. [38]

The textual part of the drawing may include information about the part, such as, used standards, used materials, manufacturing tolerances, surface textures, treatments, and so on. All of this information is transmitted as textual information traditionally. Also, drawings often relate to each other, and the information about related drawings has to be stated in each drawing to ease the work for those who need to find the related drawings. If the drawing is one of many similar drawings, the drawing may share the same drawing number with others, in which case the drawings should be separated by page numbers. Drawings are often classified by easily identifiable names. Briozzo [39] also points out that it is a common practice to make revisions of drawings, and that it has to be clearly stated which part of the drawing has been revised, when, and by who. [39,40]

2.2.2.4 Drawings for Quantity Surveying

One common practice where engineering drawings are used is in quantity surveying. Quantity surveying is the act of estimating quantities of a building or an object from available documentation. [41] The documentation can be anything that delivers the information required by the quantity surveyor, but during this study, we specifically refer to engineering drawings.

Common BIM Requirements [42] has published guidelines regarding the quantity surveying needs when making building information models. These can be useful when thinking about the future ways of consuming drawings, as the end goal for quantity surveyors is the same. Whether they take-off quantities from drawings or models, they want to understand the quantities reliably enough for the purposes of cost-analysis, material procurement, tendering, and so on. [41] Some important aspects listed in Common BIM Requirements [42] are as follows:

- The model has to be made according to requirements, and different sections of the model should not differ from the way other sections of the model has been made.

- The level of required detail has to be specified. Different parts of the model can have different level of detail in them, but it needs to be clearly stated.
- The model should be made with the correct tools provided by the software, given that the software provides tools that can be considered correct in certain cases, to make sure the quantity surveying can be done with highest possible accuracy. For instance, walls should be modeled with wall tools, if the software has wall tools.
- From the perspective of quantity surveying, different types of objects have to be identifiable. For instance, a wall has to contain the information which wall structure type the wall is. Furthermore, walls that have the same structure type, may have different heights, so from the production or quantity surveying perspective, they can be different types of wall, even though they have the same structure type.
- Following distance or measurement information are commonly used in quantity take-off: Number of pieces, length (length, height, perimeter), area measure (net surface area, gross surface area), volume measure (net volume, gross volume), weight (net weight, gross weight).
- Models should not contain duplicate objects when performing quantity take-off
- Quantity take-off divides building into following groups: building elements and building services elements (which describe the building as a physical entity), construction products (of which building elements consist of), and building services products (of which building services elements consist of).
- Quantity take-off can be done at different level of analysis. During design phase: key figure take-off, space-based take-off, preliminary building element take-off, and enhanced building element take-off. During tendering and construction phase: performance and resource based take-off or quantity take-off by location.
- Models of different disciplines overlap unquestionably (for instance, architectural and structural models both – most likely – contain load-bearing walls), thus care needs to be placed when deciding which parts will be calculated from which models.

2.2.2.5 Research Question II – Conclusions

To answer the second research question, it was suggested that drawings play a key role in the constructability of a project, as they are used as a project management tool during the pre-construction phase of a project. [33,34] Also, as Kazaz et al. [33] and French [35] point out, drawings need to be so easy to understand, that the recipient party can actually be held liable if they misinterpret the meaning of the drawing. This indeed creates a challenge when creating new technologies, as the current consensus on how engineering drawings are presented has been formed over a time-period of several centuries [2], as shown in the introductory chapter of this thesis. If the future of drawings were to include more three-dimensional representations, we can interpret Herron's [20] work to show that we would benefit in the areas of data associativity, automation, improved data exchange, time savings, data reuse, value of archived data, and reduced non-conformance costs.

It was also shown that drawing sheets as physical entities are something that have largely affected the way drawings are presented today, and on the other hand they are an outdated medium in many areas of business today. [36,37] Thus, I would argue, if the future consisted of less paper-printed products, rethinking of the presentation of the drawing objects would have to be on the table, for there are things that we assume as integral part of engineering drawings, but they may have been born out of medium requirements, rather than absolute necessity.

Finally, quantity surveying as a separate case for drawing consumption was introduced, mainly because the requirements of quantity surveyors [41] differ from the requirements of the actual builders, and thus need to be taken into account when fully articulating what drawings are or can be used for. The requirements introduced were those of Common BIM Requirements (2012), which are not the same as requirements for drawings per se, but I argue they work as a valuable reference when developing new technologies for drawing consumption.

2.2.3 Research Question III

The third research question is an attempt to discover and bring forth implicitly agreed upon ways of consuming drawings, as well as hidden potential that may abide in engineering drawings. Furthermore, this research question is a pursuit of articulating what would be worth a professional's while to get them to adopt new technologies.

> *"What are the ways in which engineering drawings are or can be used – besides the explicit ways – that can provide additional value to anyone or anything involved in the process of consuming drawings?"*

2.2.3.1 Designing Design

According to Cross (cited in [43]), in the early phases of design, engineers use drawings not to communicate ideas, but to think out loud. Martin-Erro, Dominguez & Espinosa [43] explain that visual thinking – for instance, sketching – can be considered as one of the most effective mental processes in solving problems. It allows one to play with ideas of spatial and proportional information, as well as combining objects, understanding mechanisms, and so on. One cannot simply replace sketching with verbal or other forms of thinking techniques, as it is very hard to appreciate relational information between different objects, such as size or their mechanical compatibility, without having them visually represented. Martin-Erro, Dominguez & Espinosa [43] found out in their study of the importance of sketching, that modern CAD tools do not seem to replace the need for basic sketching. This can be further reinforced by the suggestion of Ferguson (cited in [43]) that there are different kinds of sketches: Thinking sketches (to support one's thinking), talking sketches (to communicate ideas forward), prescriptive sketches (to represent ideas), and finally storing sketches (to store ideas for further need). While sketching is not the same thing as consuming drawings, one has to ask: can creation of drawings be divorced from the consumption of drawings? For instance, if one uses a *talking sketch* to communicate ideas forward during a meeting, the recipient party is consuming the *talking sketch*. I would argue that drawing creation is always linked to drawing consumption, and thus, whenever we have a process of drawing creation present – we can expect a process of drawing consumption, as well.

2.2.3.2 Implicit Presuppositions

According to Bureau of Indian Standards [44], using views in engineering drawings have to be subjected to following principles: the object should be presented with the least amount of views that can delineate the object without ambiguity, the need for hidden outlines and edges should be avoided, and the repetition of unnecessary detail has to be avoided. Thus, I would argue, the interplay of these constant forces of contradictory nature will inevitably lead to different kinds of outputs by different draftsmen. The goal is to make an optimal drawing, which should not contain too much or too little information, and to do that, one needs to constantly mediate between ambiguity and its lack thereof. Figure 5 showcases the interplay between the forces in relation to an optimal drawing.

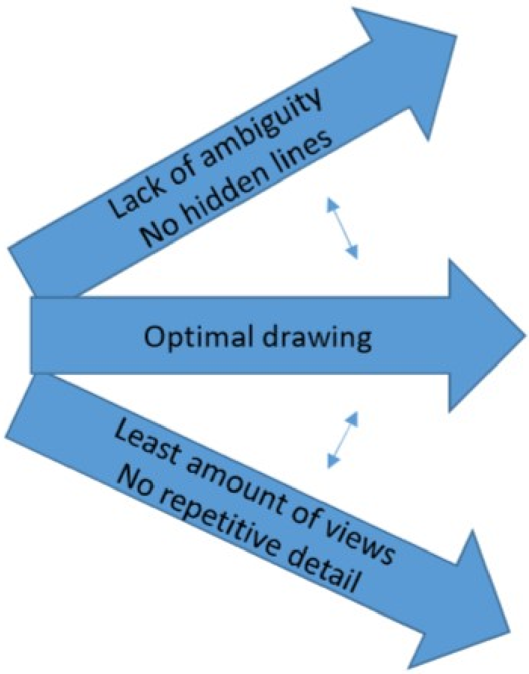

Figure 5: Mediating an Optimal Drawing Between the Competing Forces.

3.2.3.3. Example #1 of Implicit Presuppositions

We can assume that some level of implicit presuppositions have to be made in order to mediate between the forces that make up an optimal drawing. Figure 6 shows a sketch of a rectangular beam with a circular hole in the middle. Most of the people can interpret it correctly – which is the way the draftsman has intended it to be interpreted, because they trust that any information (regarding the dimensions in this example) that is left out of the drawing, can be considered easily deductible from the drawing, that expressing them explicitly would be counter-productive. Thus, the hole can be considered to be positioned in the middle in all directions in relation to the beam, and the hole can be considered circular, while it could be placed eccentrically and the shape could be slightly elliptical given the explicit information. These presuppositions can be considered tools that help mediating between the competing forces introduced above. The draftsman transmits implicit information by including *noninformation* in the drawing. Noninformation, I suggest, is information that is informative precisely because of its apparent absence. Another example of noninformation is the inclusion of only one cross-section view in Figure 6. When only one cross-section is included, the draftsman is implicitly telling that there is nothing else in other cross-sections of the part to see that would be of interest to the consumer of the drawing.

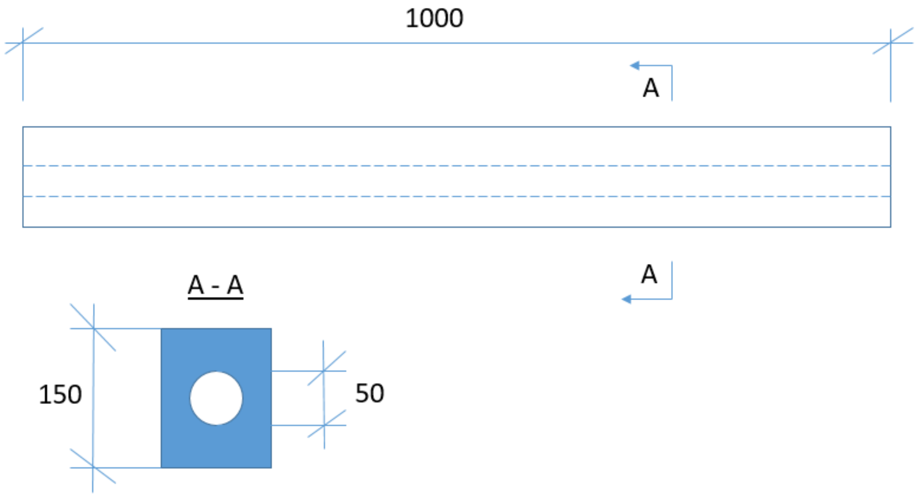

Figure 6: A Sketch of a Beam with a Circular Hole in the Middle.

While one might argue that the inclusion of noninformation as informative information is purely an individual draftsman's decision, and does not reflect upon greater social implications on the practice of producing and consuming drawings, I think it is an inevitable building block of traditional engineering drawings, given the limitations of the platform. As such, it also needs to be considered a building block – or at least a phenomenon to be taken into account – when changing the paradigm of drawing consumption. In fact, if ambiguous noninformation can be transmitted as unambiguously as possible, without causing information overload, it would make a very important building block for future practices of drawing consumption.

3.2.3.4 Example #2 of Implicit Presuppositions

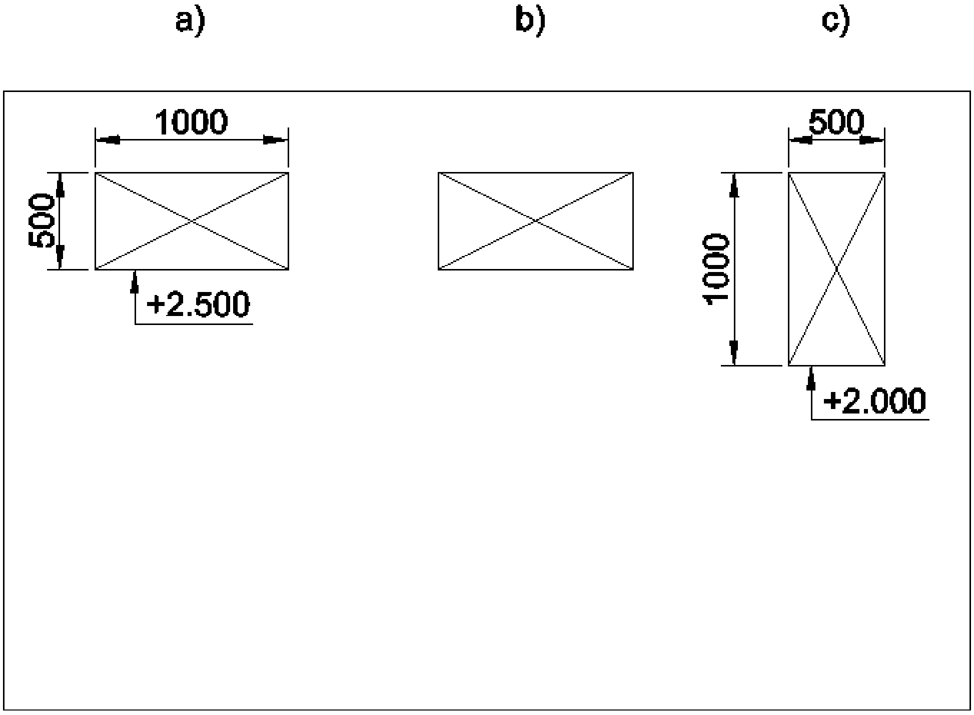

*Figure 7: Drawing Representing the Level Information of Openings **a**, **b**, and **c**.*

Figure 7 depicts a wall with three openings, ***a***, ***b***, and ***c***. Openings ***a*** and ***c*** have their level information provided, but ***b*** is without information. It is, however, completely obvious to the consumer of the drawing that the level information provided for ***a*** is applicable for ***b***, as well. This can be accounted for several reasons:

1) The consumer of the drawing is forced to view the wall from a direction, where the similarity of ***a*** and ***b*** is apparent.
2) When only ***b*** is missing information, it can be assumed that the desired information can be found from similar openings in the vicinity of the opening in question. If ***b*** and ***c*** were both missing information, it would be less obvious for the consumer of the drawing that the information for ***a*** is applicable for ***b***.
3) Providing noninformation as information is a common practice in the culture of drawing creation, thus the consumer of the drawing can assume that the information is not left out by accident.
4) The consumer of the drawing can assume that, due to structural and architectural reasons, aligning similar holes with each other makes sense, which prompts and understanding that it is very likely that the holes ***a*** and ***b*** are in fact on the same level. This interpretation may, however, depend on the type of the project, and on the level of expertise of the consumer of the drawing.
5) The drawing must be an approved final version of a drawing document, so it can be assumed that the presentation of the drawing elements have gone through proper scrutiny, and the likelihood of missing information is minute.

Thus, we can assume that based on 1), the data may be sufficient in cases when it is not only tied to the object coordinates in x, y, and z-direction, but also to the view plane that forces the consumer of the data to view the data from a certain direction.

Based on 2), we can assume that a lack of information can be information, more specifically *noninformation*. Thus, we can assume that in some cases data may manifest its full potential, only if it is paired with other data that it is intended to be paired with. Thus, we cannot assume that two pieces of information viewed separately are as informative as when viewed simultaneously. According to 3), we have to contend with the problem of culture. Culture may be something that cannot be altered with a new paradigm upfront. Then, based on 4), it can be assumed that the creator of the drawing has used reasoning that he or she shares with people exposed to the culture of engineering drawings. And finally, based on 5), we can assume that the likelihood of obvious mistakes have been driven to minimum by the result of standardized checking procedures.

These are my proposals for the reason why we can assume that the level of the opening is clear. All of these five reasons together validate each other, and thus not being able to check any one of the reasons may make understanding the level of the hole questionable without more explicit information. For instance, if the wall was viewed from an odd angle, where it would not be apparent to the eye that the holes are on the same level, we would not be able to assume that the holes are indeed on the same level. Or, if the drawing document was an unfinished version, we would not know whether the producer of the drawing has added all the desired elements onto the drawing yet.

2.2.3.3 Information Overload

Too much ambiguity can result in errors in interpreting the drawing correctly, or delays as the consumer of the drawing has to gather the information needed to get a delineated understanding of the object. Too much unnecessary repetitive information, then again, may – at least with complex objects or buildings – lead to information overload. Information overload, as described by Eppler & Mengis [45], is the act of receiving too much information that leads to rapid declination of performance. Up to a certain point, however, the amount of information has a positive impact on the performance of the individual. This correlation between information and its positive and negative effects are depicted in an inverted u-curve in Figure 8. According to Eppler & Mengis [45], the causes of information overload can be divided into five categories: Personal Factors, Information Characteristics, Task & Process Parameters, Organizational Design, and Information Technology. Personal factors can be human’s processing capacity, motivation, attitude, skills, experience, age, amount of sleep last night or lack thereof, et cetera. Information Characteristics can be the increasing amount of information, or the uncertainty, diversity, ambiguity, novelty, complexity, intensity, quality – and so on – of the information. Task and process parameters can be less routine tasks, complexity of tasks, time pressure, et cetera. Organizational design causes can be, for instance, collaborative work, centralization of information consumption, or new technologies. And finally, information technology causes can be any innovation that increases the amount of information by, for example, increasing the speed of generating information, offering vaster storage spaces, easier access to the information, or making low duplication costs for information.

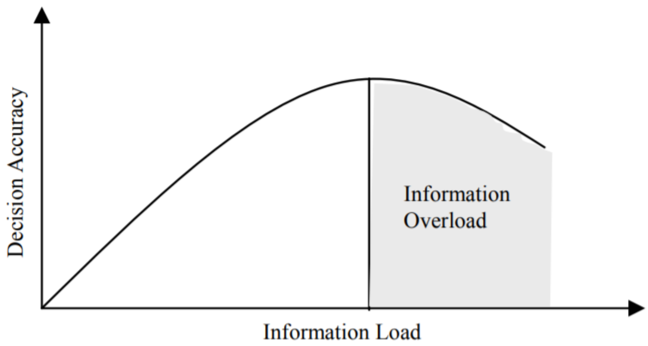

Figure 8: Information Overload as the Inverted U-Curve. [45]

As Klokholm [46] goes to show, today (his article is written in 2018) we produce 2.5 quintillion (2^{17}x5^{19}) bytes of data every day, and of the total data created in the world, 90% has been created during the last two years. He argues that BIM, artificial intelligence, and machine learning are essential in handling the vast amount of data at our disposal. While he is not primarily talking about drawing consumption per se, I would suggest that the amount of data is going to be a challenge in many fields, including the practice of drawing consumption.

2.2.3.4 Research Question III – Conclusions

To answer the third research question, we introduced several ways to produce and consume drawings that are not so obvious when only considering the final product of a finished drawing. During the creation of a drawing, the drawing is used for thinking, talking and communicating, representing, and storing. [43] As pointed out in the chapter, these are important use-cases both for the creator of the drawing, as well as the consumer of the drawing, and thus apt points when considering any possible future technologies.

Another idea introduced in the chapter were the implicit presuppositions that are so often utilized by engineers to meet the requirements of commonly agreed upon engineering drawing practices. Via two examples, I showed that engineers use *noninformation* to mediate between the contradictory requirements of avoiding ambiguity and excessive information. [37] Noninformation, I suggested, is information that is informative precisely because of its apparent absence.

Finally, while the negative effects of a lack of drawing information are rather self-evident, the negative effects of excessive drawing information may not be familiar to a wider audience. Thus, I argued that the information overload – as described by Eppler & Mengis [45] – is also applicable to the situation where we are dealing with information overload in engineering drawings. This is especially important factor when thinking about future technologies of drawing consumption, as the amount of available data today is completely different than it used to be during the advent of paper drawings. [46]

2.2.4 Research Question IV

To offer some foundation to a possible prototype, the fourth research question will try to bring about an understanding of what is it that would have to be taken into account on a theoretical level, to be able to diffuse a new technology into the population of drawing consumers.

> *"What are the critical elements – both, positive and negative – that constitute a successful diffusion process of a new technology?"*

Diffusion is the process of communicating new ideas through certain channels within a community or such that often are aimed at being diffused into the community. Diffusion can, however, happen unintentionally, too. Rogers [7] calls diffusion a "special type of communication", and he further emphasizes that communication is considered a two-way process of convergence, rather than a linear one-way act. There can be moments where a person or a community – a target group – receives one-way information, but often the target group equally teaches the change agent. One example of unknown communication from target group's side would be re-inventing the innovation, which refers to the act of using the innovation for different purposes or through different means as was originally planned. This can affect how the change agent sees the innovation. Change agent refers to a person who attempts to influence the target group's opinion or knowledge base regarding an innovation. Change agents often use opinion leaders to aid or speed up the diffusion process – or slow down, if that is the aim. Opinion leaders refer to people who are at a position where their opinion is respected by the target group, and getting these people on-board helps greatly the act of diffusion. Change agents can also use aides to narrow down the heterophilous gap between the change agent and the target group. Aides are people hired or deployed by the change agents who are often more homophilous with the target group, thus creating better grounds for mutual language with the target group. Heterophily and homophily refers to differences or similarities between certain attributes of different individuals. Rogers [7] divides the diffusion of innovations into four main categories, which are the innovation, communication channels, time and the social system. [7]

Innovations always create a certain degree of uncertainty in the target group (is it easy to adopt, will it work, how does it function, and so on), while they simultaneously represent reduced uncertainty with their improved processes, which provides the motivation for change for the target group. This balance of advantages and disadvantages is called the relative advantage, which is one of the five perceived attributes that make up a big portion of a successful diffusion process. Other attributes are compatibility, complexity, trialability and observability. These characteristics vary in importance depending on the innovation, and they affect the innovation-decision process of the target group. Innovation-decision process refers to the process of the target group first time hearing about the innovation, to forming an opinion on it, and either rejecting or accepting the innovation. Rogers [7] has divided the innovation decision process into five main steps: knowledge, persuasion, decision, implementation and confirmation. While the process either leads to rejection or acceptance of the innovation, the decision can actually be reversed later, if the innovation, for instance, improves in a way that the target group wants to accept the innovation after rejection. It is also worth pointing out, that the innovation-decision process has been divided into four types by Rogers [7], which are optional, collective, authority, and contingent innovation-decisions. The acceptance happens in an s-shaped form, which refers to the time span of different groups of adopters adopting the innovation. The adopter groups are innovators, early adopters, early majority, late majority and laggards. See Figure 9 for the s-shaped curve, to better understand the position of the adopter groups. While the groups and the s-shaped curve are universal, the slopes of the shape depend on other variables that affect the adoption speed of the innovation. [7]

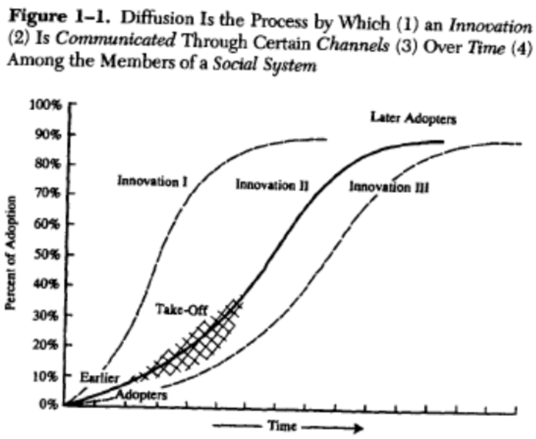

Figure 9: S-shaped adoption curve of innovations. [7]

Individuals always operate in social systems, whether the boundaries of the system have been predefined from above (for instance a department of an organization) or the group has been formed inherently over time (for instance a group of friends). When talking about diffusion of innovations, all the members of the system are trying to solve a common problem that binds them together. All the social systems have a structure, which allows people to predict behavior to some degree, thus creating stability and predictability. In the diffusion process, understanding the social structures is of high importance, as they can have a great effect on the enhancement or the mitigation of the odds of a successful diffusion. As Rogers [7] put it, “individual innovativeness is affected both by individuals’ characteristics, and by the nature of the social system in which the individuals are members”. Furthermore, social systems have the systems’ norms, which are the established behavioral patterns that define what kind of behavior is accepted and expected. Even a group of friends have system norms that need to be followed, which obviously may be different from the system norms of the society they live in. Thus, understanding all these overlapping systems and system norms requires a great deal of study of the target group. A diffusion process can lead to different kinds of consequences, which Rogers [7] has divided into three classifications: desirable vs. undesirable consequences, direct vs. indirect consequences and anticipated vs. unanticipated consequences. [7]

2.2.4.1 Perceived attributes

Rogers [7] explains that the five formerly introduced perceived attributes constitute a majority of the variance in the rate of adoption of innovations. He describes relative advantage as "the degree to which an innovation is perceived as being better than the idea it supersedes". Relative advantage can be measured monetarily, socially, and in any other way that may be important to the adopter of the innovation.

Compatibility, then again, "is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters". Familiar user-interface, for instance, may increase an innovation's rate of adoption, as it is in line with the past experiences of the adopter. [7]

Complexity is a self-explanatory term, but Rogers [7] explains that rather than the actual complexity of an innovation – the perceived complexity of the innovation is the one that matters when measuring the rate of adoption. Complexity is a relative measurement, and thus the adopter's perceptions matter – whether they consider the innovation complex or not. The more complex the innovation is perceived to be, the lower the rate of adoption. [7]

Trialability refers to the innovation's capability to be tried before the implementation of the innovation. Observability refers to the possibility of observing the results of the innovation. If the innovation is trialable or observable, the rate of adoption tends to be higher. [7]

2.2.4.2 Brand Value and Compatibility

As Rogers [7] describes, compatibility is one of the five perceived attributes that constitute a successful diffusion process. This can be linked to Holt's [47] framework of sustaining brand value. Holt [47] introduces the framework that we will call an identity magnet framework, which consists of three segments of consumers: the followers, the insiders, and the feeders. Figure 10 presents the framework of the consumer segments in relation to the brand. All of these consumer segments play an important role for the brand, but they all create uneven value to the brand. To avoid unnecessary abstraction, let us suppose that the brand we are discussing here is a BIM software with a long history in steel structures and a tendency to offer cutting-edge technological solutions to the market.

Followers are the group of users who identify with the technological brand in this case. They prefer the brand in question to other brands, and they believe in the myth propagated by the brand, which could be "the best BIM software in steel industry", for instance. Insiders are the group of users of the brand who put great emphasis into making sure that – as far as they are concerned – the software in question is seen as the original and perhaps the best solution available. The insiders may – for instance – participate in the development of the software through customer feedback programmes, and furthermore, they value their relationship with the company. The insiders feed the brand with respect and legitimacy, as long as the brand propagates a correct message through marketing the product image and delivering solutions. Feeders are the group of people who are not necessarily interested in the brand, but are consuming the product or products because of the status-enhancing gravitational pull of trendiness and awareness created by the insiders and the followers. They may change to other solutions if the brand identity magnet is not strong enough to pull a big group of people to consume their products. [47]

All of these consumer groups introduced above are important in terms of brand value, but the insiders and the followers are the ones who create the identity magnet for the brand. They are often a smaller group of people compared to the feeders, but they bring an enormous amount of value for the brand, because if they respect the myth the brand delivers, a big group of feeders will be attracted with the identity magnet created by loyal fans. Through understanding the consumer segments, it helps the design business managers to focus on the brand and to understand why the consumer segments are so important to the brand. That, for example, further allows the managers to find the right balance between new ideas and traditionality, without altering the existing consumer base. This, in turn, ties to the idea of compatibility of Rogers [7]. The changes in the technological solutions have to respect the existing offering to sustain the brand value through user interaction. [7,47]

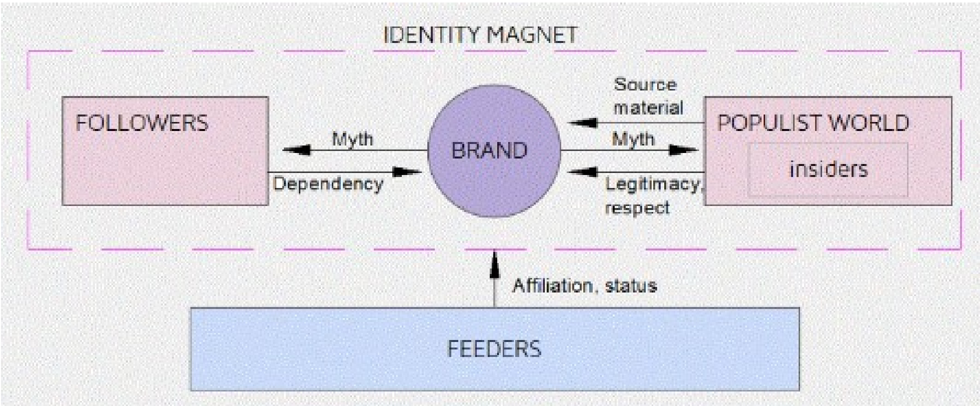

Figure 10: The Identity Magnet Framework. [47]

2.2.4.3 Research Question IV – Conclusions

The fourth research question was on purpose more focused on the qualities of the future technology, and what should be taken into account when designing a prototype, rather than trying to answer the intellectual question at hand. The idea was mainly to articulate the means by which the technology could be propagated to the clientele, so that a paradigm shift would be possible in reality, too.

To tackle this challenge, we introduced Everett Rogers' five perceived attributes [7], that are designed to address means by which the diffusion process of an innovation can be enhanced to some degree, for the diffusion process needs to reach a certain range of people, before – if at all – it becomes self-propagating. The five perceived attributes are *relative advantage, compatibility, complexity, trialability,* and *observability.* I also connected Douglas Holt's Identity Magnet [47] to the idea of compatibility – as this is an important factor when creating a prototype – by showing that not losing contact to the inside users of the software, as well as feeding the follower users with the correct brand image, is of high importance in terms of brand value. It is essential to point out the connection between brand value and the possible diffusion of a new technology, as one may wreak great havoc if trying to introduce a new technology that does not serve the requirements of the existing clientele, I argue.

When we proceeded to create the prototype, Rogers' five perceived attributes [7], as well as Holt's identity magnet framework [47], functioned as a sort of bench mark – to the degree that it was possible – that told us what aspects needed to be addressed in the prototype, for the interviewees to be able to find interest in the prototype. The prototype creation process was approached by ensuring its relative advantageousness, matching it to the existing values and past experiences of the users, avoiding perceivable complexity, and making it trialable and observable.

3 Proof-of-concept Study

The second part of the thesis was to create a prototype that could be used as a practical tool to study the needs, the requirements, and the wishes of the clientele regarding new means of consuming drawings. Also, a prototype is a great tool for concretizing the more abstract ideas found during the theoretical part of this research and the more practical ideas that emerged from the client interviews, into one quasi self-explanatory prototype, that the interviewees could then assess and observe. Finally, a prototype is a first step towards a paradigm shift, as the industry has to start somewhere the process of a paradigm shift, which, according to Kuhn [6], either happens completely or not at all.

The proof-of-concept study consisted of several phases that all served the purpose of collecting information for the purposes of prototype creation, as well as reinforcing and further advancing the theoretical findings of this research. The different phases of the proof-of-concept study were conducted in following order.

- *First round of interviews*: to understand the needs, the requirements, and the wishes of the clientele regarding new means of consuming drawings
- *Prototype*: based on the theoretical research findings and interview findings, a prototype of a technology was produced to concretize the ideas.
- *Second round of interviews*: confirming that the concrete ideas presented in the prototype are in fact something that would be of importance or use to the clientele.
- *Final analysis of the prototype*: drawing conclusions from the interview data and articulating the next steps for the prototype, and conducting a quality function deployment analysis on the prototype.

3.1 First Round of Interviews

3.1.1 Interview Setting – First round

Out of some seven requested interviewee candidates five agreed to partake in the interview, all of whom represented the field of professional structural engineers with different levels of experience and different disciplinary backgrounds. As most of the requested participants agreed to partake in the interview, and they represented the population of professional structural engineers with a wide spectrum, the risk of ending up with a *highly selective sample of individuals* [48] – who in reality do not represent the total population of professional structural engineers – can be considered low. As the interviewed people were selected and not randomly picked, the method is considered stratified sampling rather than random sampling, as described by Lancaster. [49] The time horizon of the interviews was cross-sectional, because the interviews were arranged at a single point of time. [50] The interviews were arranged for each individual separately, during a time period of one month in the autumn of 2018. The professionals who partook in the interview are introduced in Table 1.

Table 1: List of the Interviewees.

Interviewee A	Highly experienced professional with some 20 years of history with BIM and software development
Interviewee B	Highly experienced professional with over 20 years of history with BIM and project management
Interviewee C	Experienced engineer with degrees of structural engineering and construction architecture and 3 years of history in structural engineering
Interviewee D	Experienced engineer with a degree in construction engineering and 3 years of experience in on-site construction management
Interviewee E	Experienced engineer with a degree in construction engineering and 2 years of experience in on-site management and in quantity take-off

Due to the variability in professional history and different disciplinary backgrounds, semi-structured interviews were a good alternative that allowed for some variation in the wording of the questions, as well as for probing for more information and for clarification when needed. The interviews were face-to-face interviews, which, according to Barriball & While [48], are beneficial for appreciating non-verbal communication, and for ensuring that the respondents formulate the answers by themselves, and for increasing comparability as the interviewer can probe for more accurate answers, among other reasons. The interview lengths varied between 45 minutes and 75 minutes, and they were recorded for later utility. The fact that all the interviewees allowed to be recorded, and they were positively engaged in the activity, is an indication that the data can be considered reliable in that respect, as Barriball & While [48] point out.

3.1.2 Interview Questions – First Round

The interview questions were formulated in a manner that was in line with the theoretical findings – validating, enrichening, and further diversifying the findings. For instance, the question "*what different purposes do you use drawings for?*" was based on a presupposition that drawings are indeed used for more than what meets the eye. As was discussed in chapter 2.2.2, one person may use drawings for extracting out information that is crucial for the building of an end product, while another person may use the same drawing for extracting out quantities for tendering purposes. Thus, the question was an attempt – to not only verify these findings – but to uncover more ways of using drawings. Furthermore, the interview question formation was conducted in a manner that would allow the answers to be comparable with each other. As suggested by Barriball & While [48], the interview questions – in addition to their informative content – were subjected to two other main criteria: the questions were formed so that the interviewees could and would answer the questions, and so that the answers would bring about differences in the attitudes, views, and perceptions between and among the respondents. The semi-structured interview skeleton can be found in Appendix I.

3.1.3 Data Analysis – First Round

The data consisted of recorded audio files of the interviews that were later transcribed into accurate text files containing all of the information in a written form. The original interviews and transcriptions were in Finnish, so the translation into English took place during the coding process of the interviews. The general process of the data analysis was based on Braun & Clarke's [51] phases of thematic analysis. As Braun & Clarke [51] point out, the phases are a guideline rather than strict rules, which is why during this study the steps were borrowed not strictly but to serve our goal of producing results, not only for a scholarly research, but also for the purposes of the upcoming prototype. The exact steps followed during the first round of the interviews are introduced in Table 2, which is an altered version of Braun & Clarke's phases of thematic analysis. [51]

Table 2: First Round of Interviews – Altered Version of the Steps of Thematic Analysis by Braun & Clarke. [51]

Familiarizing oneself with the data	Transcribing data, reading and re-reading data, noting down initial ideas.
Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code. Translation to English during coding.
Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme.
Reviewing themes	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
Analyzing the data for the prototype	Selection of interesting ideas onto a report for the purposes of prototype creation. Producing a holistic overview of the needs, the requirements, and the wishes that emerged in the interviews regarding the prototype.
Producing the final report	Final analysis for the purposes of the theoretical part of this research. Selection of vivid, compelling extract examples. Final analysis of the selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

According to Braun & Clarke [51], thematic analysis is an easy process to learn and to do, and easily accessible to a researcher who has little to no experience of qualitative research. This increased the likelihood of not conducting an erroneous process of the thematic analysis. The answers from the first round of interviews were analyzed as qualitative data using thematic analysis. The data was approached using inductive approach, which Braun & Clarke [51] describe as bottom up approach, where the data is confronted with an open mind and the themes are – to some degree – emergent properties of the data, although by no means exclusively, as the interview questions most certainly direct the answers. The transcribed interviews were coded and categorized into themes, which were then prioritized and utilized in the prototyping process, as well as in answering the research questions of this research project, in order to include the most important elements of the interviews into the body of knowledge of this topic.

3.1.4 Interview Findings – First Round

The interview data consisted of 330 individual quotes or summaries of ideas that were then coded through several rounds of iteration using 14 different codes. These codes were then further amalgamated into 7 different code groups, and finally these code groups were placed under 4 different themes of discussion. The codes, code groups, and themes are presented in Figure 11. Although inductive approach was used to handle the data, the themes did not just emerge from the data as inherent properties of the data, but were also affected by the interview questions, and their formatting. Thus, the themes do not explicitly exclude other potential themes in the area of drawing consumption. On the other hand, the interview questions were based on the theoretical research findings, and thus provide a rather unbiased platform for finding the themes. So, I would argue, the findings are a good contribution to the body of knowledge of drawing consumption, but they do not exhaust the field in any sense.

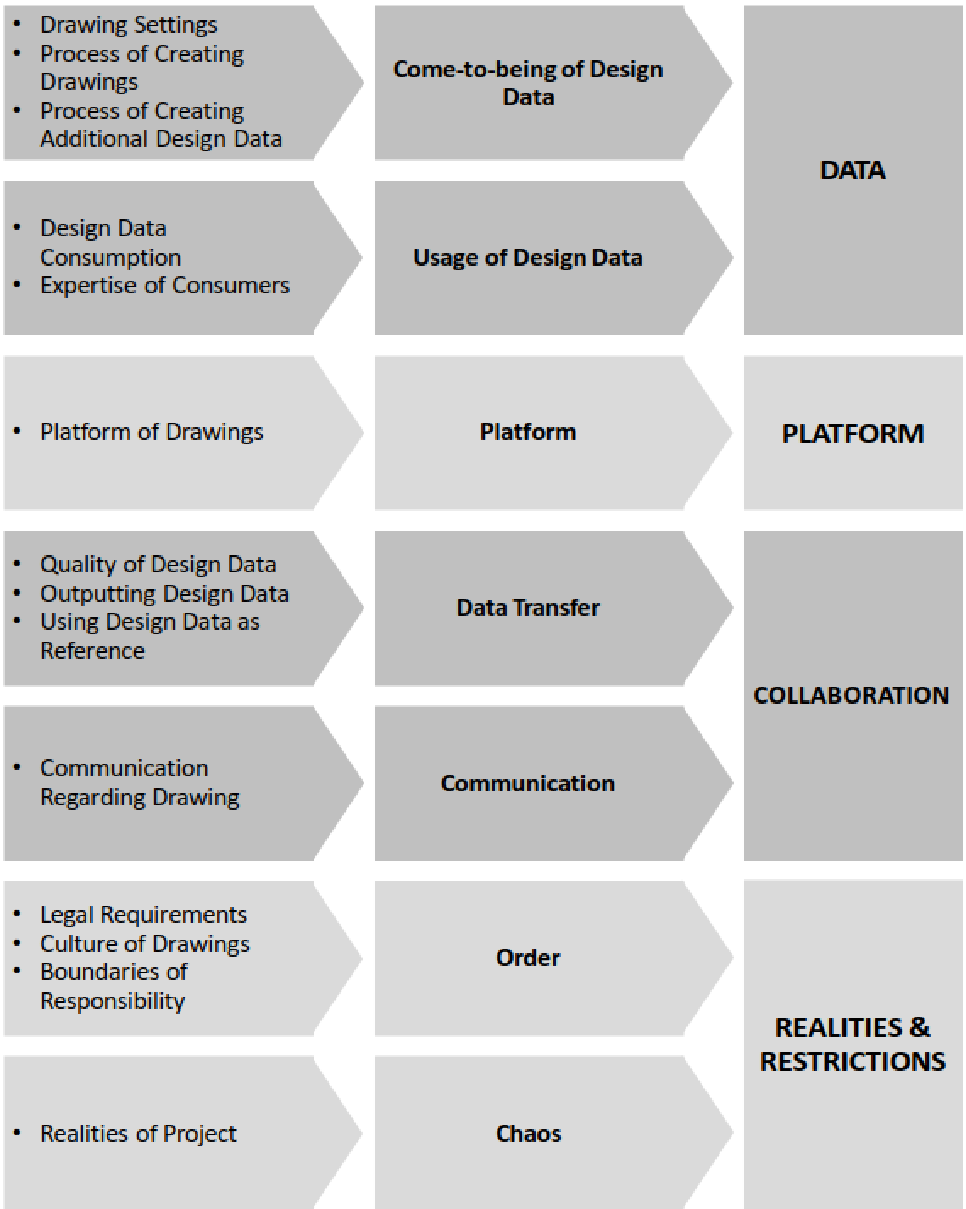

Figure 11: Codes, Code Groups, and Themes of the Data Set Found From the First Round of Interviews.

As presented in Figure 11, the four main themes of discussion were *Data*, *Platform*, *Collaboration*, and *Realities & Restrictions*. The codes on the leftmost column describe less abstractly what the topics discussed under the themes were. Data in the discussions refer to design data itself or anything directly linked to the qualities of properties of design data. Platform, then again, refers to the platforms of consumption of drawings. Examples of platform discussions would be paper as a medium, the utilization of 3D environment for consuming drawing documents, and the benefits of a PDF reader, to mention but a few. Collaboration refers to any action that utilizes drawings or design data in a collaborative manner – whether it is human to human, human to machine, or machine to machine. Hence, both design data transfer and communication as such are placed under the rubric of collaboration. Finally, realities & restrictions as a theme contains all the topics that either cover the legal requirements, boundaries of responsibility, cultural factors, or realities of a project. The code group titles order and chaos emancipate the topics from their restrictive codes, and thus, virtually any orderly or chaotic factors can be placed under the code groups order and chaos.

In addition to the codes, the code groups, and the themes, each one of the 330 individual quotes or summaries were marked whether they contain a wish or not, and whether they contain a concrete idea or not. A wish meaning something that the interviewee presented as a problem that they would like to see technology solve in the future, and a concrete idea meaning something the interviewee had a vision about on how technology could shape the future. An example of a wish is presented by *Interviewee E,* who would like technology to solve the problem of extracting quantities off a ready-made drawing that does not contain explicit information about the said quantities. It is a wish, as he has a problem he would like technology to solve, but has not presented a concrete suggestion on how this problem could be solved. An example of a concrete idea is presented by *Interviewee B,* who suggested – when discussing about modifying drawing information – that it should be possible to just add a dimension on a drawing, and then the consumer of the drawing could immediately see the same dimension at their workstation. This is a concrete idea, as it clearly provides a solution to a problem, although by no means an exhaustive solution. Out of the 330 individual quotes or summaries, 39 contained either a wish or a concrete idea, which means 11.8% of the answers. This is an expected result, as the target of the interviews were not to collect new ideas, but rather to map out what really is important to the population of drawing consumers. In fact, the interview questions did not contain any questions probing for wishes or concrete ideas, as the first and foremost focus of the interviews was to answer the research questions. It was expected that the concrete ideas for the prototype could be extracted from the interview data, but it was a surprise to some degree that there were so many articulated ideas and problems that could be utilized immediately. The total amount of codes were 565 codes, so each quote or summary were assigned with 1.71 codes on average. The division between codes can be seen in Figure 12. While the amount of codes highly differ between the themes they represent, it does not mean that the validity of a theme or its lack thereof can be derived from the amount of given codes, as was pointed out by Braun & Clarke. [51]

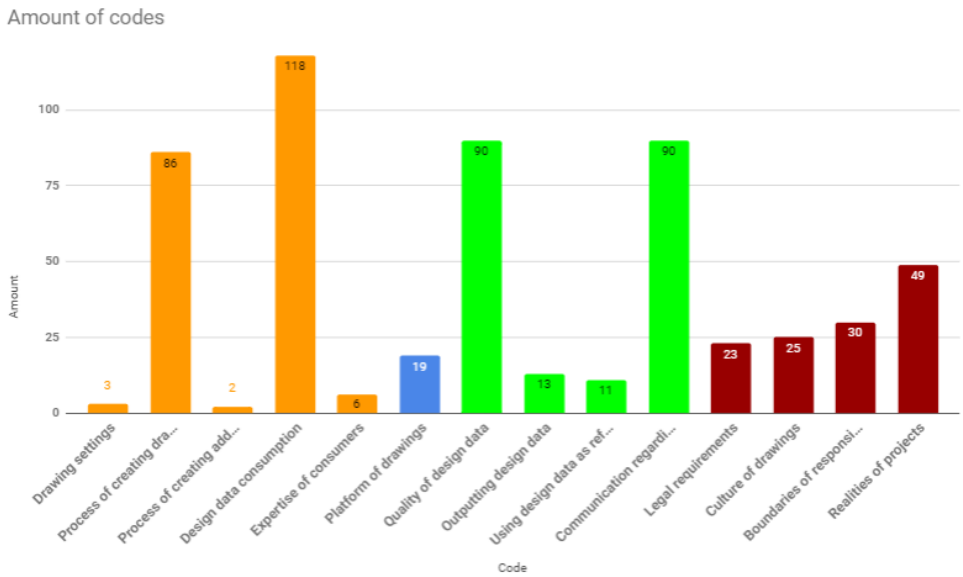

Figure 12: Amount of Codes in Each Code Group in the First Interview.

3.2 Prototype

The creation of the prototype was a sequence of divergent and convergent processes, where a quick-and-dirty prototype would be made, after which the content of the prototype would be assessed more critically. Then another prototype would be made, with a little more sophistication than the previous one, just to be torn apart by the convergent process again. Convergent thinking refers to the act of finding out the most reasonable solution through a process of deductive reasoning, while divergent thinking refers to the creative process where a person experiments with ideas that are loosely connected to each other. [52] The final prototype, which seemed to be good enough for the purposes of this research project, was version number five. The prototype was then refined from a quick-and-dirty version to a clickable mockup that would look professional, so that the second round of interviews would not be interfered by the low quality of the prototype. As the funding organization of this thesis owns the software called *Tekla Structures*, and all the interviewees were either familiar with the software, or at least had experimented with it before, the prototype borrowed the user interface of Tekla Structures. The findings, however, are not targeted toward any one software, but can be read independently.

3.2.1 Prototype Content

The prototype consisted of seven different topics, each of them containing clickable objects, pictures, videos, and animations, making it – at times – feel like the user is actually using a real software, and in other sections, they would see an animation, for instance. The seven topics introduced in the prototype were: *Basic logic, Design data creation, Communication using design data, Data-cluster content, Change management, Ensuring printability,* and *Different platforms.* A screenshot of the prototype in Figure 13 shows how the design document dimensions would appear to the user in a 3D environment.

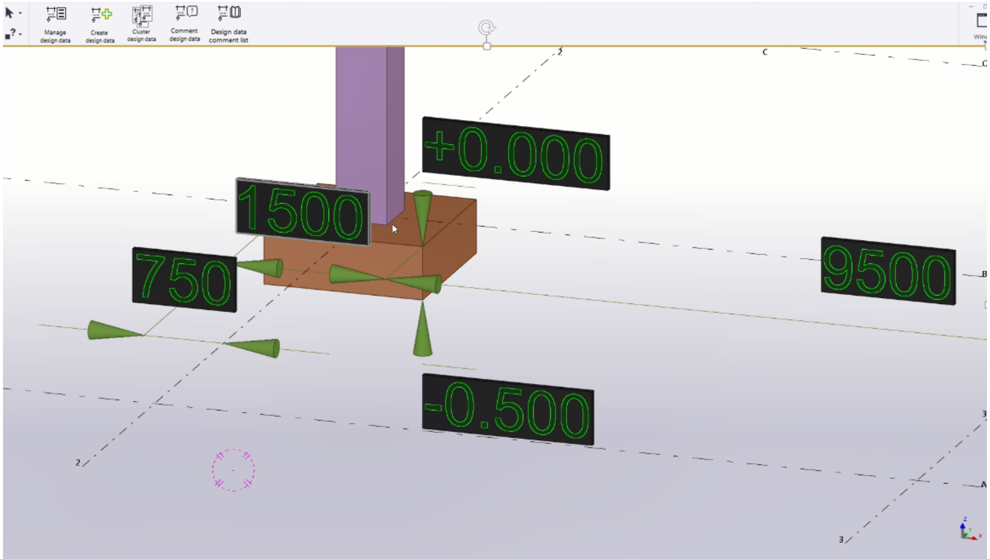

Figure 13: Screenshot of the Prototype Dimensions in a 3D Environment.

3.2.1.1 Basic Logic

The whole logic of the technology, which, I suggest, could be instrumental in bringing about a paradigm shift in the field of drawing consumption, is presented in Figure 14. The idea is that in the future drawings – which we would call design documents, as they would no longer have the paper restrictions nor the drawing layout of 2D necessarily – would be primarily consumed in a 3D environment. The said design documents would be consumed using a BIM software that would be accessible through different locations and different platforms as it would be hosted on a cloud server. This would be in line with the technology findings of chapter 2.2.1. We would introduce a new data set called *Design data set* into a 3D environment, which would replace the need for a traditional drawing document. Design data sets would be constructed of four main elements, *Data-clusters, View filters, Start view,* and *Properties.*

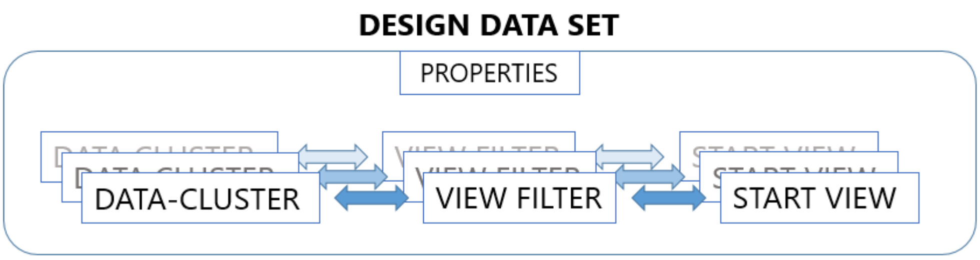

Figure 14: Design Data Set.

- Data-cluster is a cluster of data, formed of individual pieces of design data, which together form a sensible unity in relation to each other. As pointed out in chapter 2.2.3 of this thesis, individual pieces of data are less informative than when they are combined together, revealing noninformation. Thus, it is very important that data-clusters form unions that provide coherent information in relation to each other.
- View filter is a rule that differentiates within the 3D environment which objects of the 3D model needs to be included and which objects need to be excluded from the viewing session. Inside a design data set, it would have

to be related to the proposed data-cluster, as the presented data combined to the presented views form a meaningful union of information, as suggested in chapter 2.2.3 of this thesis. Similarly, the view filter would have to be connected to the start view.

- Start view is the starting direction and distance of viewing in relation to the 3D model. It is information that takes all the viewers of the design data set to the same initial position, so that all the consumers of the design data set can be expected to have the same experience when reading the design data in the 3D environment. As argued in chapter 2.2.3 of this thesis, viewing direction is essential in delivering the correct message to the reader. And delivering the correct message is a desired goal, because drawings – or design documents in this prototype – are documents where the consumer of the drawing can be held liable for misinterpreting the information, as French [35] pointed out.
- Properties would contain all the information that is not specific to the viewing direction, objects, or data-clusters. Such information would be, for instance, the name of the designer of the design document. This information would not have any other natural place, as the object in the 3D environment might be designed by a different party than the final design document. Properties could also be other external attributes that were presented in chapter 2.2.2 of this thesis, such as linked documents.

The three interlinked elements presented above (data-cluster, view filter, start view) form a coherent set of information that deliver a sufficient union of information for the purposes of design information transmission. These three elements would always be connected to each other, so that at minimum a design data set would contain at least one data-cluster, one view filter, and one start view. There could be more than one set of these interlinked data, however. Properties, then again, would be any external data that is not presented in the three interlinked elements. Figure 15 is a screenshot of the prototype, where all the elements of a design data set can be seen in the user interface.

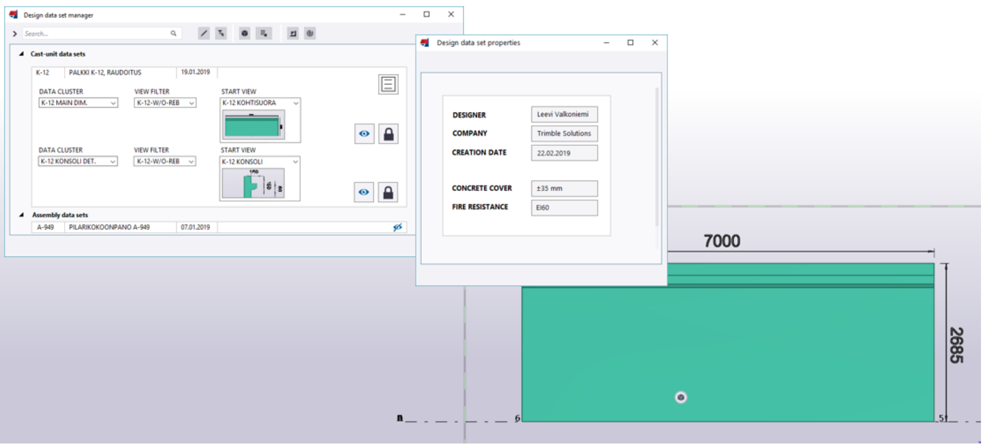

Figure 15: Screenshot of the Prototype Displaying all the Elements of a Design Data Set.

3.2.1.2 Design Data Creation

As argued in chapter 2.2.3 of this thesis, the creation and consumption of design data – while separate processes – cannot be divorced completely. A good example is given by Interviewee D during the first round of interviews. As an on-site construction manager he needs to create safety planning on the basis of a ready-made design document. Traditionally he would take a paper drawing and use a pencil to draw safety railings onto the drawing. Now, he is a consumer of that design document, while he is also a creator of a new design document that is based on the old document. Another example is given by Interviewee B, who points out that sometimes the consumer of the drawing contributes to the creation of the design document by commenting on the design document, for instance, by saying that a dimension is missing. Thus, he contributes to the creation, but also is a consumer of the design document. Figure 16 is a screenshot of the section of the prototype where one would engage in the creation of design data.

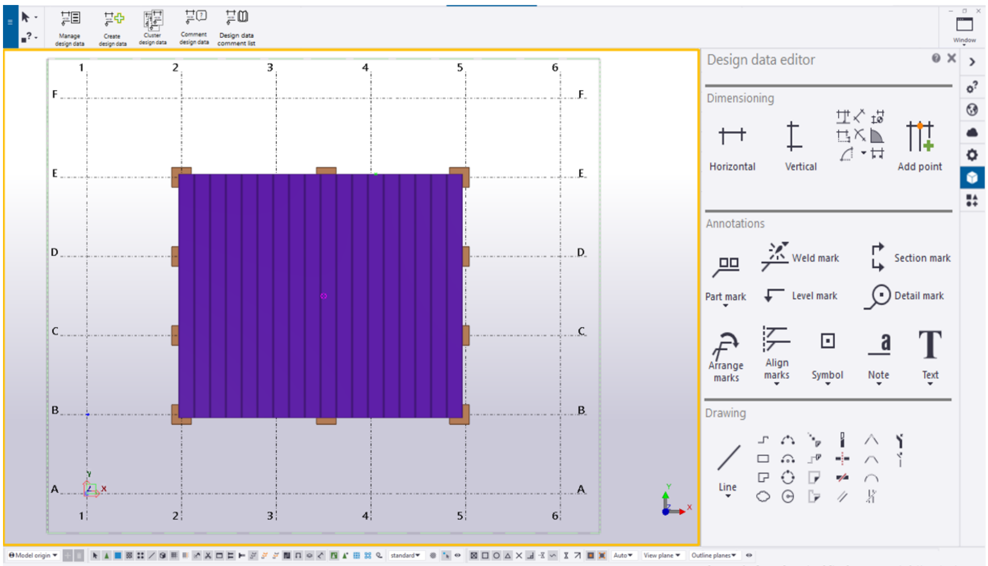

Figure 16: Design Data Creation Tools in a 3D Environment.

3.2.1.3 Communication Using Design Data

As discussed in chapters 1.1 and 2.2.3 of this thesis, the act of using design to communicate ideas back and forth is something that is inherent to graphical content, including engineering drawings. Furthermore, 15.9% of the codes of the first interview were placed under the code *Communication regarding drawing,* which means it was a topic that was widely discussed with all the interviewees. Of course, as was mentioned in chapter 3.1.4, the discussed topics do not directly correlate to the importance of a topic per se. Nevertheless, a considerable weight was put on the communication tools of the prototype.

All of the interviewees had had issues with communication when consuming drawings. As Interviewee B put it, being in a higher position and not creating drawings by himself anymore, "*It is absolutely idiotic that you call the engineer and tell them a dimension is missing, and you get it a couple of days later. It is not enough that the engineer tells you the dimension, because you need to get the revision drawing to keep it official.*" Also, interviewee C talked about a similar situation, being a structural engineer himself, he explained that the solution is to send an e-mail first, and later make the official revision. This, however, increases workload, as one has to solve the issue first and later make the official changes to the documentation. The prototype provides a suggestion to this dilemma by allowing the consumers of the drawing to create dimensions onto the design document themselves, after which they can choose whether the dimension – or any other design document annotation, for that matter – is a temporary dimension or if it should be sent for approval. This way, the consumer of the design document becomes a contributor of the design document simultaneously, and all the changes can be accepted or rejected by the responsible party in real time – without them having to go and produce the design document again. Figure 17 is a screenshot of a situation within the prototype where one has selected an annotation object, and has a drop-down list of two choices in this suggestion.

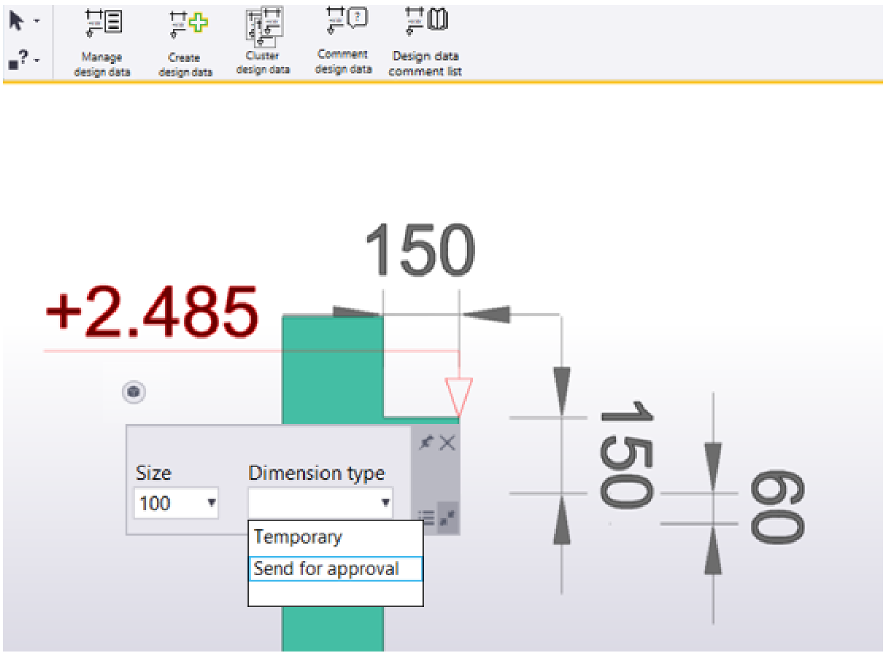

Figure 17: Communication Regarding Newly Created Design Document Objects.

The slowness of communication is not the only challenge to be handled regarding design documents. Another challenge is the presence of multiple simultaneous conversations regarding multiple different objects at once. This conversation management happens via e-mail, telephone, and during face-to-face meetings, either official or unofficial. Official being a meeting where minutes are recorded, and an unofficial meeting would be any encounter where no official records are made but information is exchanged. In addition to traditional conversations where two or more people exchange information, Interviewee D – an on-site construction manager – said he has to take photos of different phases of the project. Not necessarily to converse with other people, but to have as back-up, if someone later wants to know whether something was done correctly, for instance.

> *"In one project customer suspected that their bathroom doesn't have floor heating installed. I sent them the photographs to show him that they were definitely*

installed there. And the electrician checked that there is electricity running." – Interviewee D

To accommodate this wide range of information, the suggestion in the prototype is to provide a design document level conversation management tool. This would allow conversations between the parties to be recorded within the software, or simply uploading documentation, including meeting minutes and photographs that are related to the selected design document. The tool would consist of a tool where one could send messages, or simply record messages, upload files, set due dates, assign tasks to people, set priorities for the task, and so on. This part of the tool is inspired by *Trimble Connect*'s ToDo –tasks [53], but is brought into a completely new environment, allowing conversation management in the design document level. A screenshot of the commenting tool is provided in Figure 18. Figure 19, then again, shows the design data comment list, which would be a record of conversation events within the design document.

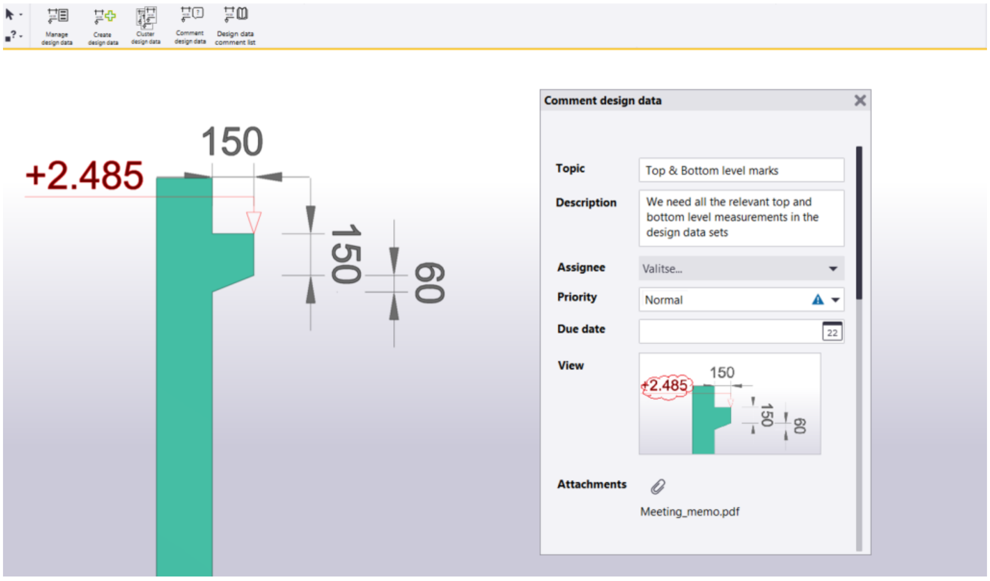

Figure 18: Design Data Comment Tool.

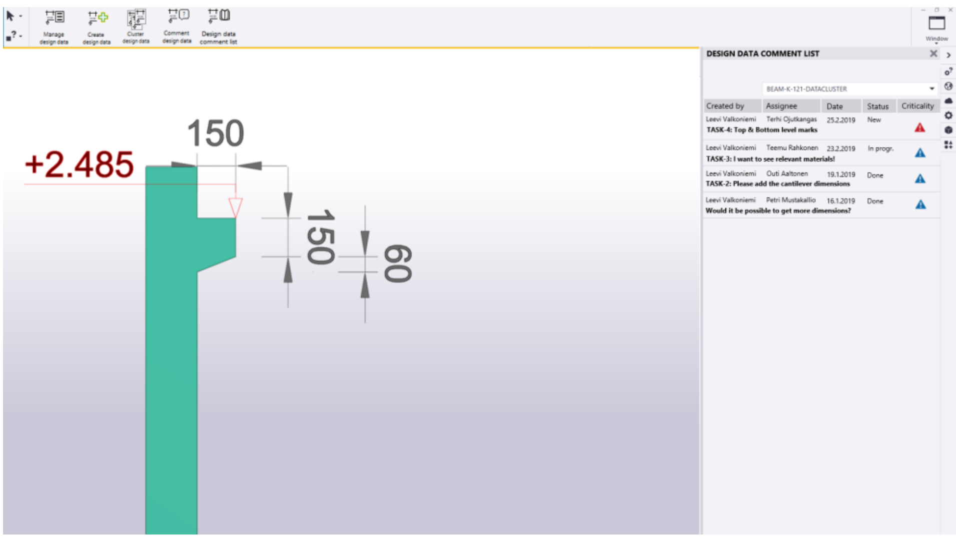

Figure 19: Design Data Comment List.

3.2.1.4 Data-cluster Content

As explained earlier, data-clusters would be one of the three interlinked elements of a design data set. While view filters and start views are existing entities within different BIM software, data-clusters are a new suggestion specifically related to this prototype. Data-clusters, I suggest, would be a cluster of data, formed of individual pieces of design data, which together form a sensible unity in relation to each other. As data-clusters are particular to this prototype, explaining what they consist of in a more practical manner seemed important. Figure 20 shows an example of a data-cluster of a reinforced beam that is consisted of different kinds of individual annotations, specifically reinforcement, dimensions, and level marks. All of these data are placed under the category of *Location-based data*, as their presentation at a certain location and in relation to each other and the object is crucial. A possibility of non-location-based data is reserved for the data-cluster, but in this example, only the name of the data-cluster is data that is not based on location.

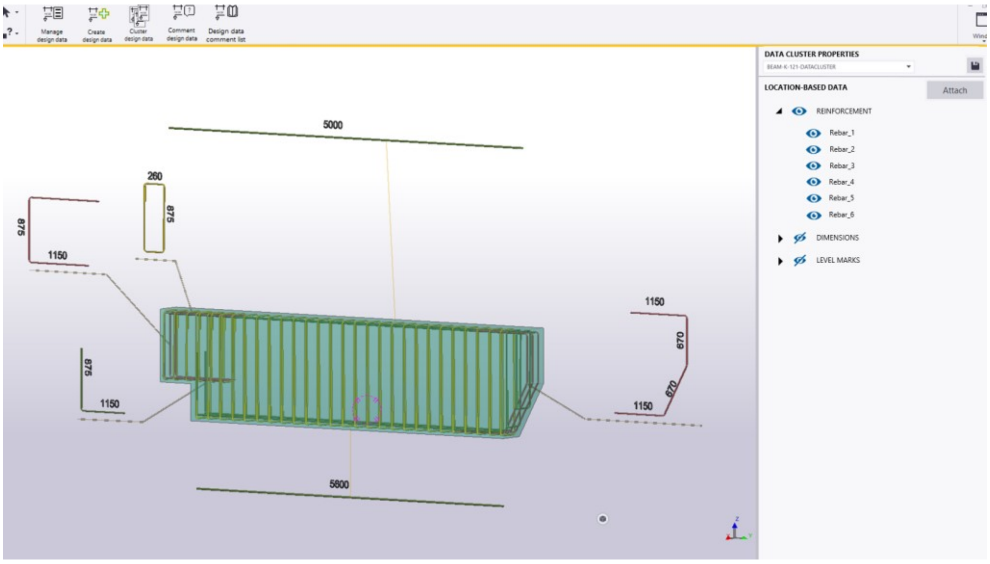

Figure 20: Data-cluster Content.

This example addresses interviewee ideas, too. The screenshot of Figure 20 shows that the reinforcement bars are denoted as *Rebar_1, Rebar_2, Rebar_3,* etc. within the data-cluster. This would allow the consumer of the drawing to hide or show the reinforcement bars in the correct order of installation. This was, in fact, a customer idea that was presented by Interviewee A. He pointed out that showing the order of assembly of objects would be something he would like to see in future drawings. At the moment, they have to show the order of assembly at different sections of the paper, losing the dynamicity that 3D could otherwise provide. Similar worries were presented by Interviewee C and D.

> *"We have tried to explain the order of installation with some textual information, but also by having discussions with the representatives of the construction site about how something should be made." – Interviewee C*

3.2.1.5 Change Management

As discussed in chapter 2.2.2, revisions are the change management tool of traditional engineering drawings, showing the consumer of the drawing what changes has been made, when, and by who. [39] Addressing change management was crucial, as this was brought up by all the interviewees multiple times, when discussing changes in the content of the drawings. The way revisioning is handled currently has some pitfalls that the new technology should or could address. The first issue is the apparent slowness of transmission of information that was already discussed in chapter 3.2.1. Another issue was brought by Interviewee C, who mentioned that downloading the wrong revision from the project bank is a real risk, because only the newest revision is the one that is needed for building. He said that often times he might call the site that a new revision is coming or is out, because the current solutions do not function exactly in real time, as one still has to – after making the actual changes – print the drawing, open a different software, and upload the documents where the consumer of the drawings hopefully finds them as soon as possible. To mitigate these risks, the change management tool suggested in the prototype is a real-time change management list that is interactive with the design document itself. If one were to make changes to the design document, the changes would, after acceptance, be visible to all the relevant parties directly, and no further printings, markings, or other time-consuming activities would have to be carried out. The changes would be visible upon clicking on the change management list, and they would be highlighted in blue, as is shown in Figure 21. The change management tool would be a design document level tool, meaning that the changes would be recorded to the proper place directly, and the design document would always be up-to-date.

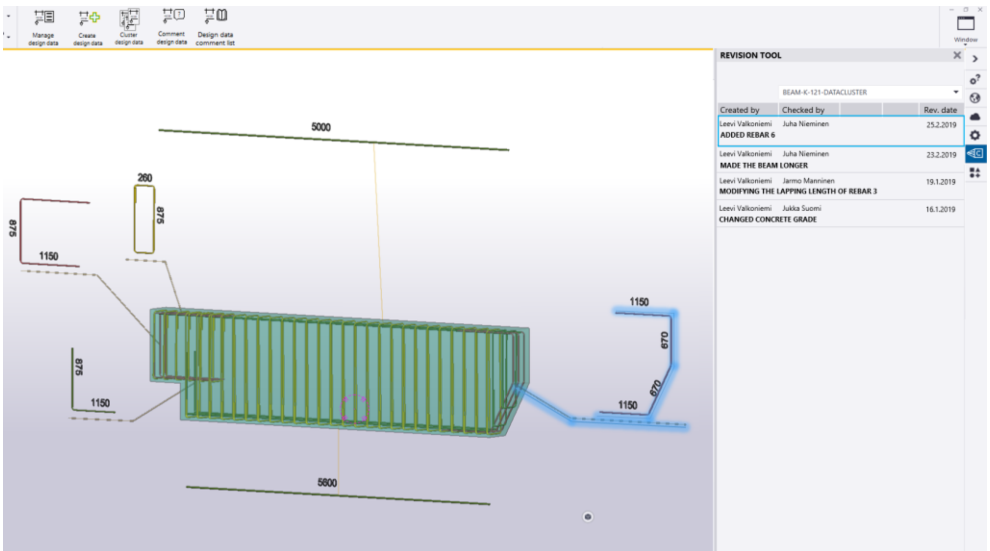

Figure 21: Change Management Tool of the Prototype.

3.2.1.6 Ensuring Printability

Ensuring printability was a direct wish from all the participants of the interviews, as they could not conceive a future where the printed end-product of a design document would cease to exist altogether. As Interviewee A said, you can read paper drawings on a dirty construction site even if it is raining. On one hand, everyone agreed that complete voidance of paper drawings would seem unreasonable and perhaps counter-productive, but on the other hand, all of the interviewees did find drawings clumsy or unuseful in some situations. For instance, Interviewee D said papers are sometimes so big that they are actually really difficult to use, especially if you compare to a drawing consumed on a tablet computer where you could just zoom in and out when viewing a design document. Furthermore, as Interviewee C said, sometimes the problem – from the perspective of the one who is making the drawing – is that you cannot fit all the desired drawing views into the paper, which then multiplies the amount of drawings – something that is not considered an ideal outcome either. These interview findings reinforce and enrichen the conclusions that were derived from literature in chapter 2.2.2. Furthermore, in chapter 2.2.1 I argued that drawingless and paperless engineering are targets of the industry, and as such, this suggestion would provide a natural step toward a future where the importance of paper and drawings would be mitigated. It may seem unreasonable at first to allow for the old and the new way to coexist, but as Thomas Kuhn [6] pointed out from a more philosophical perspective: *"During the transition period, there will be a large but never complete overlap between the problems that can be solved by the old and by the new paradigm. But there will also be a decisive difference in the modes of solution. When the transition is complete, the profession will have changed its view, its methods and its goals."*

Based on the interview findings and the literature findings, the prototype provides a possibility to print paper drawings, although the primary means of consumption is a 3D environment. The idea is that one could simply drag-and-drop the desired design data sets onto a paper sheet, and then print them to any desired format. The paper would not be an environment where one could change the contents of the drawing, except for layout positioning and other information that is particular to the printed product. This creates a flexibility that would allow one to print only the things that are required when someone crucially needs a paper drawing, for example, as was said, if they are building outside in the rain. Whatever can be consumed electronically, would then be consumed electronically. Furthermore, the main official design document would be the electronic version, and the paper print would be a mere reflection of the official document. Figure 22 is a screenshot of the part of the prototype, where one could choose to print a design data set onto a paper.

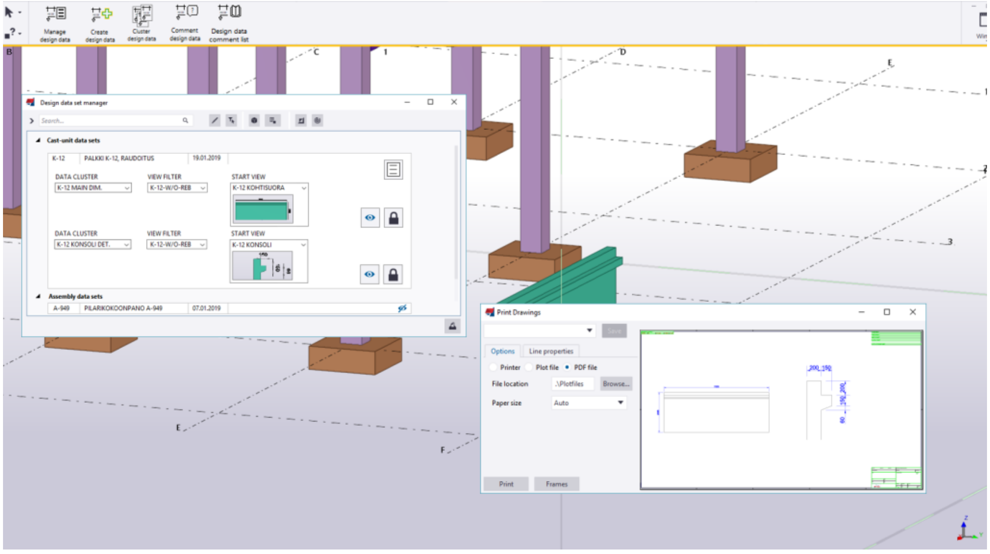

Figure 22: Screenshot of the Printing Tool of the Prototype.

3.2.1.7 Different Platforms

Based on the literature findings that were introduced in chapter 2.2.1, some of the technologies or ideas that we can assume to be essential in bringing about a paradigm shift in the field are taken into account as integral part of the prototype. For instance, while the prototype does not explicitly introduce mixed reality as a concept, the prototype has been built so that it could accommodate mixed reality platforms. The design documents, for instance, could be consumed in a mixed reality environment. Interviewee A also pointed out that although paper drawings are necessary sometimes, the combination of different platforms is the most efficient one. Sometimes you may want to consume something using one platform, and then another thing using another platform. Similar remarks were made by other interviewees, as well. Other technologies that were introduced in chapter 2.2.1, which are baked into the prototype are drawingless and paperless engineering, cloud computing, and building information modeling. Different platforms, such as cellphones, tablets, and mixed reality glasses are a natural part of the solution, as the documents can be simultaneously consumed in different locations, by different people, using different devices. All the interviewees said that they sometimes consume drawings either using cellphones or tablet computers, but Interviewee D pointed out that it is not exactly comfortable with a cellphone. Figure 23 is a screenshot of the prototype presentation where different platforms of consumption were introduced.

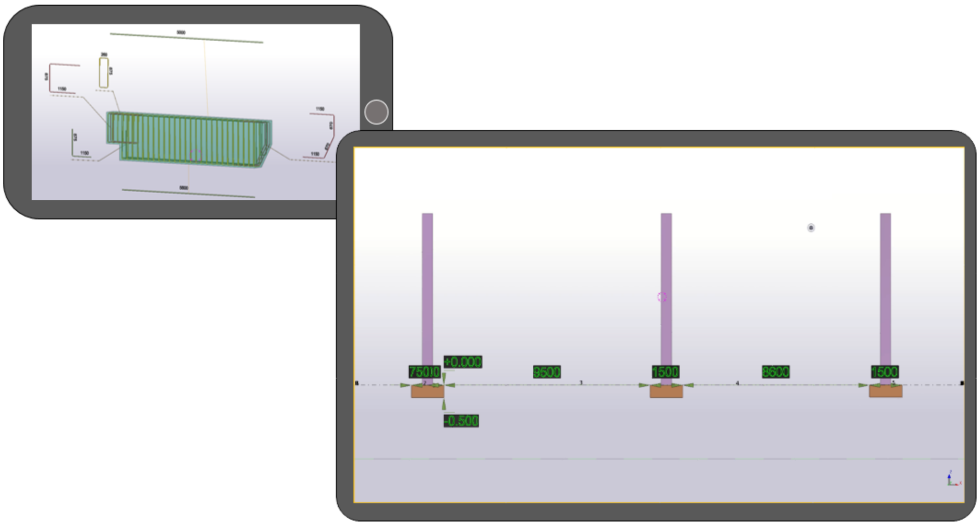

Figure 23: Screenshot of the Prototype Presentation with Different Platforms of Consumptions.

3.3 Second Round of Interviews

3.3.1 Interview Setting – Second Round

All of the five interviewees who participated in the first round of interviews, also agreed to partake in the second round of interviews. This can be considered a beneficial set up, as the prototype was heavily based on the interview findings – alongside the literature findings, and during the second round of interviews the interviewees could confirm whether their statements have been understood correctly. The second round of interviews were arranged for each individual separately during a time period of one month in the spring of 2019.

The second round of interviews were arranged as semi-structured interviews. Instead of a set of questions, however, each section of the prototype was first introduced to the interviewee, and then they were asked what positive and negative aspects they find in this section of the prototype. The interviews were face-to-face interviews, which, according to Barriball & While [48], are beneficial for appreciating non-verbal communication, and for ensuring that the respondents formulate the answers by themselves, and for increasing comparability as the interviewer can probe for more accurate answers, among other reasons. The interview lengths varied between 45 minutes and 60 minutes, and they were recorded for later utility. The fact that all the interviewees allowed to be recorded, and they were positively engaged in the activity, is an indication that the validity of the data can be considered reliable in that respect, as Barriball & While [48] point out.

3.3.2 Interview Questions – Second Round

The second round of interviews did not contain a set of questions, like the first round of interviews did. The second round of interviews effectively used the prototype as the interview foundation. As the prototype consisted of seven distinct topics, each topic was introduced first, and after the topic was introduced – i.e. the interviewees were shown the logic in action – the interviewees could get to pose questions, and evaluate what things they find positive in the prototype and what things they find negative in the prototype. This approach is in line with the suggestions by Adams [54], who – as discussing about the conduct of semi-structured interviews – points out that close-ended questions can be a good gateway to open-ended questions. For instance, when they are shown a feature in the prototype, and asked whether they like it or not, that is a close-ended question, which can be used for analysis in and of itself. That is then followed by an open-ended question of "why or why not?" to probe for more elaboration.

3.3.3 Data Analysis – Second Round

The data consisted of recorded audio files of the interviews that were later transcribed into accurate text files containing all of the information in a written form. The original interviews and transcriptions were in Finnish, so the translation into English took place during the coding process of the interviews. The general process of the data analysis was based on Braun & Clarke's [51] phases of thematic analysis. As Braun & Clarke [51] point out, the phases are a guideline rather than strict rules, which is why during this study the steps were borrowed not strictly but to serve our goal of producing results, not only for a scholarly research, but also for the purposes verifying the suggestions presented in the prototype, and furthermore, to test the hypotheses from the literature presented in chapter 2. The exact steps followed during the second round of interviews are introduced in Table 3, which is an altered version of Braun & Clarke's phases of thematic analysis. [51]

Table 3: Second Round of Interviews – Altered Version of the Steps of Thematic Analysis by Braun & Clarke. [51]

Familiarizing oneself with the data	Transcribing data, reading and re-reading data, noting down initial ideas.
Applying pre-existing framework of codes and themes onto the data	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code. Translation to English during coding. The codes of the first round of interviews were used as a pre-existing framework.
Reviewing themes	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2).
Analyzing the data for the prototype	Selection of interesting ideas onto a report for the purposes of confirming the findings of the earlier parts of the study. Producing a holistic overview of the needs, the requirements, and the wishes that emerged in the interviews regarding the prototype.
Producing the final report	Final analysis for the purposes of the theoretical part of this research. Selection of vivid, compelling extract examples. Final analysis of the selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

According to Braun & Clarke [51], thematic analysis is an easy process to learn and to do, and easily accessible to a researcher who has little to no experience of qualitative research. This increased the likelihood of not conducting an erroneous process of the thematic analysis. The answers from the second round of interviews were analyzed as qualitative data using thematic analysis. The data was approached using deductive approach, which Braun & Clarke [51] describe as top down approach, where the data is confronted with a specific goal in mind and the codes and themes can be – as they are in this case – brought forth via pre-existing framework. The pre-existing framework in question were the codes and themes of the first round of interviews, which were then mechanically applied onto each quote or summary, to be able to compare the findings of the second round of interviews to the findings of the first round of interviews.

3.3.4 Interview Findings – Second Round

The interview data consisted of 139 individual quotes or summaries of ideas that were then coded using 14 different codes, 7 different code groups, and 4 different themes of discussion. The codes, code groups, and themes are presented in Figure 11 in chapter 3.1.4. The interview questions – in other words, the prototype – were based on the first round of interviews and the literature findings. The goal of the second round of interviews was to primarily confirm the findings and suggestions provided in the prototype, and secondly, to contribute to the body of knowledge of drawing consumption.

In addition to the codes, the code groups, and the themes, each one of the 139 individual quotes or summaries were marked whether they contain a wish or not, and whether they contain a concrete idea or not. A wish meaning something that the interviewee presented as a problem that they would like to see technology solve in the future, and a concrete idea meaning something the interviewee had a vision about on how technology could shape the future.

Out of the 139 individual quotes or summaries, 12 contained either a wish or a concrete idea, which means 8.63% of the answers. This is an expected result, as the target of the interviews were not to collect new ideas, but rather to map out whether the interviewees find the ideas presented in the interviews valid or not. In fact, the interview questions did not contain any questions probing for wishes or concrete ideas, as the first and foremost focus of the interviews was to confirm the validity of the findings presented in the form of a prototype. The total amount of codes were 325 codes, so each quote or summary were assigned with 2.34 codes on average. The division between codes can be seen in Figure 24. While the amount of codes highly differ between the themes they represent, it does not mean that the validity of a theme or its lack thereof can be derived from the amount of given codes, as was pointed out by Braun & Clarke. [51]

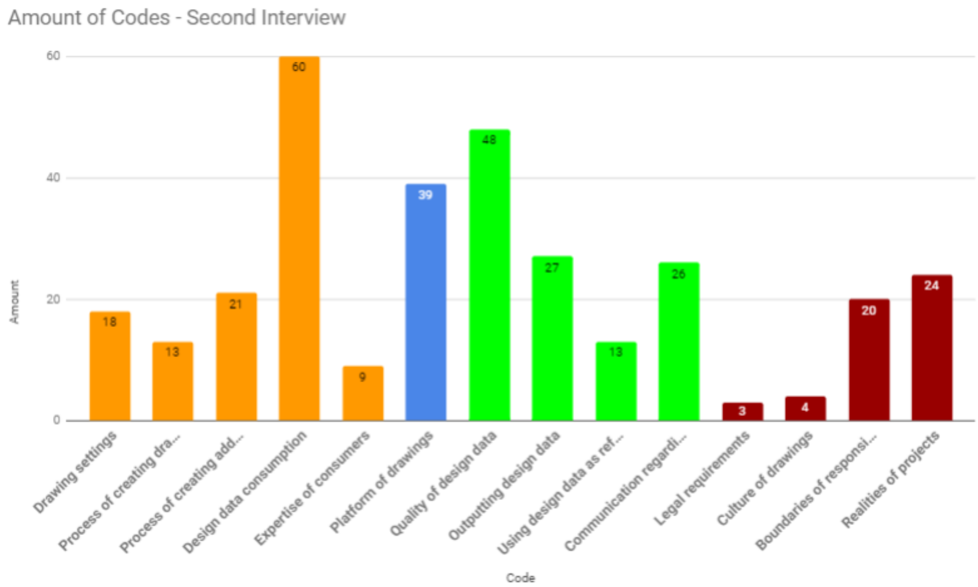

Figure 24: Amount of Codes in Each Code Group in the Second Interview.

3.4 Final Analysis of the Prototype

After the thematic analysis of the interview data, the final analysis of the prototype included a section-by-section study of the prototype and the data, by deriving out quotes or summaries that seemed to form coherent collective agreements on what should be taken into account if this technology was developed further, and what the interviewees found useful or interesting. The prototype consisted of seven different sections: *basic logic, design data creation, communication using design data, data-cluster content, change management, ensuring printability,* and *different platforms.* In addition to the interview data analysis, a quality function deployment (QFD) analysis was carried out to test the compatibility between actuality and the literature and interview findings, and on the other hand, to provide tools and foundation to further utilize the prototype in research or development. An online questionnaire preceded the QFD analysis to map out customer opinions on the analyzed topics.

3.4.1 Summary of the Next Steps of the Technology

3.4.1.1 Basic Logic – Next Steps

43 out of 139 quotes or summaries were discussed under the section of basic logic of the prototype, meaning that a considerable time of the interviews was spent discussing the logic of the technology. The general impression towards the prototype was positive but cautious. Interviewee E suspected that the technology would benefit them with improved interoperability of different design documents and help them to locate problems at an earlier phase of the project. Interviewee C and D both expressed that they would need to try the prototype in action, to be able to give feedback more confidently. This is in line with the theoretical findings Introduced in chapter 2.2.4. According to Rogers [7], trialability and observability are among the five attributes that encourage a diffusion process of a technology. Based on Rogers' five attributes [7], the prototype was made into a clickable prototype so that some level of trial and observance could take place.

The main worry people had was whether the technology would be easy to use and easy to access. Interviewee C suggested that a democratic platform, similar to PDFs that basically anyone can open, would be ideal for this kind of technology, as anyone has to be able to open the design document. The prototype indeed was designed so that it could be run on different platforms and on a cloud server, utilizing the technologies that were introduced in chapter 2.2.1. This is something, however, that would need more specification in future studies. Interviewee A pointed out that usually BIM software provide a lot of data that is not so clearly structured, so the problem of excessive data would have to be addressed also, as was pointed out in chapter 2.2.3.

Interviewee D liked the idea that he could print out drawings on the go, and from the angles and with dimensions that would specifically suit his needs. Interviewee B pointed out the contrasting risk that if one has too much possibilities in terms of selection, the user experience may suffer. Besides the possible complexity of the user experience, all the interviewees were confident that a 3D environment for design documents would increase the readability of the documents, and make it easier especially for people who are inexperienced.

Finally, Interviewee A thought that this technology is not going to replace paper drawings due to weather conditions, and other external factors that simply make paper superior in comparison to a tablet, for instance. While Interviewee B was also skeptical about the vicinity of the future of completely paperless industry, he was more optimistic and suspected that a solution will emerge at some point.

3.4.1.2 Design Data Creation & Communication Using Design Data – Next Steps

Due to a presentational choice, and the closeness of these topics in the prototype formation, the feedback for design data creation and communication using design data were collected simultaneously. Thus, their findings are introduced in this chapter together. 26 out of 139 quotes or summaries were discussed under the sections of design data creation and communication using design data. The general consensus was that the commenting and design data creation together would form such a strong unity, that it would make work considerably faster and easier.

> *"Sometimes I need to comment that something is wrong, so I take a GA-drawing and mark there what is wrong. Then take a copy of it, and e-mail it to the engineer. So that* [the suggested way] *is definitely faster, like 10 or 100 times faster, when I can directly just comment there, instead of taking copies and e-mailing." – Interviewee D*

Interviewee A pointed out, however, that the suggested comments do not make much sense to a BIM coordinator, although they may be useful to a person dealing with less information. In BIM coordination, he explained, the problem is that people often get many different screenshots, reports, explanations, views, and so on. Thus, instead of a comment that contains a screenshot, he would want to see the technology embed the information directly into the model object. Furthermore, from a point of view of a BIM coordinator, he would like to see the approval process to be more centralized, so that one would not have to approve things one by one, but rather in a more sophisticated manner.

Finally, a common theme among the interviewees were that this technology would help drawing the lines of legal boundaries and the boundaries of responsibility. Interviewee B, for instance, pointed out that a simple list of communication – that would be accessible to all the relevant parties – would facilitate clarity between the boundaries of responsibility of different parties. Similarly, Interviewee A suspected that it would bring transparency to the table, if instead of a final document, the relevant parties could see the whole history of communication regarding a design document. Interviewee C wondered, however, whether there would be a risk of assigning tasks to wrong people. This is something that would need to be addressed carefully when developing the technology further.

3.4.1.3 Data-cluster Content – Next Steps

17 out of 139 quotes or summaries were discussed under the section of data-cluster content. This was an important section in terms of explaining the prototype, as data-cluster as a concept was self-developed for this particular technology suggestion. All the interviewees, rather unanimously, agreed that the inclusion of data-clusters into the concept of drawing consumption would make reading the documents easier, as it would allow one to freely choose what design document annotations they want visible or invisible. Interviewee B pushed it even further, and would like to see the objects themselves to be similarly adjustable, not just the design document annotations.

It was also suggested in the presentation, that this functionality could be used for sequencing purposes, so that the engineer could show which parts of the drawings should be installed in what order. This suggestion, although generally considered a positive suggestion, was thought to exacerbate the worries of complexity. Interviewee C – an engineer himself – feared that workload would increase, while

Interviewee E – being an on-site manager – worried whether he could rely on the sequence. Furthermore, Interviewee D – also an on-site manager – pointed out that usually there is only one way to install parts, and that is the correct way. But in complex scenarios, he thought, this feature could be useful.

3.4.1.4 Change Management – Next Steps

14 out of 139 quotes or summaries were discussed under the section of change management. Generally the interviewees considered the suggested change management to be visually clearer than the old way of pointing at the changes with an arrow. Interviewees E and D, however, raised an issue with compatibility. This is in line with the theoretical findings presented in chapter 2.2.4. Compatibility, according to Rogers [7], "is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters".

> *"I don't see any issues with this idea. I'm only thinking how people – who have been used to work in a certain way – would like this. We have all kinds of processes and ways of working, and some people just prefer the old way, while others are more accepting." – Interviewee E*

Another important point was raised by interviewees B and C, who both pushed the idea even further, saying that it should be possible not only to see *where* the changes are, but *what* they are. Of course, one can visibly examine the changes even in the current suggestion, but an example inspired by Tekla Structures was given by Interviewee B.

> *"You could signify different kind of changes with different colors. Removed parts could be displayed with red color, modified parts with yellow color, and so on. Similar to IFC comparison in Tekla Structures." – Interviewee B*

3.4.1.5 Ensuring Printability – Next Steps

21 out of 139 quotes or summaries were discussed under the section of ensuring printability. During the first round of interviews, all the interviewees unanimously agreed that getting rid of paper altogether is not an alternative at this point. Whether it will ever be an alternative, however, was a more diversely approached topic. The insistence on the necessity of paper forced me to think how the prototype would still ensure printability, while trying to push forward the consumption of design documents in a 3D environment. The prototype suggestion was generally well received. Interviewee D, for instance, said that offices could save thousands of euros – even up to tens of thousands of euros – in printing costs per project, if the amount of printed paper were to be dropped drastically. Also, the general usability and the possibility – but not necessity – of printing was considered

as an improvement to the different ways the engineer are familiar with at the moment. As Interviewee E pointed out, they may print a set of drawings today, just to find them revised tomorrow, and print them again. As they use a printing service, costs accumulate and time is consumed more than would be necessary if every drawing did not have to be printed.

One worry both Interviewee B and C shared was the apparent slowness of the printing process as suggested in the prototype. They would like to see less manual work and more artificial intelligence induced solutions, where the user would not have to drag-and-drop the desired data sets onto the printed paper, but that most of the work would be done without them contributing to it manually. This is indeed in line with the theoretical findings of chapter 2.2.1.

Interviewees A, D and E all agreed that this would benefit their daily tasks, if they could print any model view into a paper with the dimensions and objects they need in their particular situations, without destroying the dynamicity provided by a 3D environment by making modifications on the paper environment. Interviewee C, however, provided a contrasting opinion, that sometimes changes only to the paper environment are a life-saver – if not a necessity – when the documents need to be published immediately.

3.4.1.6 Different Platforms – Next Steps

18 out of 139 quotes or summaries were discussed under the section of different platforms. The idea is that these design documents would not be limited to a certain device, but could be read on different platforms and devices. Generally tablets, cellphones, mixed reality glasses, and the like, were considered apt platforms for this technology. Interviewee D thought, however, that cellphones are quite useless due to their small size. Interviewee E, then again, suspected that foldable phones [55] will be an answer to this size issue. Interviewee B even more boldly suggested that in the future we may see a paper material that is effectively digital. These suggestions are tightly linked to the findings presented in chapter 2.2.1 that IoT and big data will play an important role in the paradigm shift of the field.

Also, complexity was a worry to some users if, for instance, the prototype was run on a cellphone, but on the contrary, the possible advantages of reading the documents on the go alleviated the worries of the interviewees.

> *"Even a mouse is a complex tool in comparison to your index finger." – Interviewee A*

Interviewees C and D were both exuberated about the possibility that the platform thinking would allow different parties to utilize the technology in their work. Interviewee D, for instance, pointed out that even authorities could check that the structures have been built according to the design documents, by comparing 3D documents to the final product. Interviewees B and C, however, pointed out that the platform has to be absolutely democratic – so that one does not have to have a certain device – to be able to consume the documents. Interviewee B suggested that the platform should essentially be on a cloud server, which you could access with a browser. Interviewee C suggested a similar idea, and pushed it even further, by bringing in the idea of Youtube –links. Youtube –links can bring you to any second of the video. [56] Similarly, by sharing links, he suggested, you could be taken into any design document directly. This way you could control the access rights and on the other hand attain a democratic solution for a platform.

3.4.2 Quality Function Deployment Analysis

After assessing the interviewee data, the final part of the proof-of-concept study consisted of conducting a quality function deployment (QFD) analysis on the prototype. QFD, as described by its founder Yoji Akao [57], is a product development method that makes all the processes of the development phase transparent. The idea is to start off by mapping customer demands and continue to determine design quality and instill quality planning. Product quality, according to Akao [57] is conducted of many different factors, and they affect one another in a way that no human being can manage alone. Thus, a thorough QFD provides a platform for managing that network of qualities in a way that is understandable, and helps the person utilizing the QFD report to prevent problems from materializing, to manage the relational information between different points of data, and to provide as good a product as possible to the final customer. [57] The QFD analysis during this research consisted of two parts. An online questionnaire that was used to map out information required by the QFD process, and the actual conduct of the QFD process.

3.4.2.1 Questionnaire

The first step of QFD is to solicit customer requirements. [58] As the QFD in the case of this particular research had been preceded by a de facto customer requirement solicitation process, the customer requirements were readily available by a data analysis of the first and second round of interviews. To perform a proper QFD analysis, however, the customer requirements need to be numerically assessed, so that the correlations between different customer requirements and the technical product specifications can be measured. [58] Thus, an online questionnaire was conducted to collect numerical values for the customer requirements. The questionnaire was sent to the same five customers who had partook in the interview process. Three out of five customers responded to the questionnaire, so the response rate was 60%, which is adequate for the purposes of this research. The questionnaire and the customer requirements can be found in Appendix II.

3.4.2.2 Quality Function Deployment

The customer requirements obtained from the interview data were converted to *technical and measurable statements*, as Haag et al. [58] describe the resulting units of conversion. There were in total 13 different customer requirements, and 15 different technical statements that were converted from the customer requirements. One customer requirement can be transformed into more than one technical measure [58], and thus the technical measures outnumber the customer requirements. To give an example, customer requirement “availability for different devices and platforms” was converted into two technical statements, “number of supported devices” and “number of supported operating systems”.

After laying out the technical measures, they were denoted by using arrows or a hyphen to determine whether a higher or a lower value is better, or whether it cannot be estimated. By using an upward pointing arrow (↑), the technical measure was deemed to improve if its value was higher. Similarly, by using a downward pointing arrow (↓), the technical measure was deemed to improve if its value was lover. Finally, by using a hyphen (–), neither a higher nor a lower direction value could be given to the measure. This does not necessarily mean that the hyphenated measure does not exhibit a desired direction, but rather, for instance, that improvements to both directions could be considered an improvement from some perspective, and a simple up or down would not suffice. An example of a technical measure that was denoted with an upward pointing arrow would be “amount of time saved”, which is a measurable statement, and everyone would most likely agree that the more time is saved the better. An example of a technical measure that was denoted with a downward pointing arrow would be “number of clicks to reach the desired goal”. The less clicks the better. Finally, an example of a hyphenated measure would be “amount of buttons on the user-interface”. While some people could argue that it is obviously bad to have multiple buttons on the user-interface as they slow down your work, someone else could consider it a positive thing that signifies the software’s versatility and capability. Thus, a measurable direction cannot be given.

The next step of the QFD analysis was to assess the correlation between each of the technical measures. As there were 15 different technical measures, there were 105 correlational values to be given. The correlations were assessed on a scale of minus two to two (-2…2), minus two being a highly negative correlation, zero being a neutral correlation or a debatable correlation, and two being a highly positive correlation. An example of a highly negative correlation would be the correlation between the statements “amount of time saved” and “number of clicks to reach the desired goal”. If one is building a time saving system, a high number of clicks to reach one’s desired goal seems to be negatively correlated to that goal. An example of a highly positive correlation would be the correlation between the statements “number of clicks to reach the desired goal” and “amount of preset settings/installations required to be able to open a design document”. If reaching a goal requires as small number of clicks as possible, then similarly the effort for opening a design document can be expected to be lower as well. Finally, an example of a neutral or a debatable correlation would be either something that has no apparent correlation, or has a correlation that can be considered either negative or positive depending on the perspective. For instance, the correlation between the statements “amount of time saved” and “amount of supported devices” can be considered neutral, as there is no apparent connection between these two statements. Of course, one could argue that the more supported devices you have, the more likely it is that all the parties of the project could use the software, and thus speed up the project by means of a successful technological diffusion. But similarly, one could argue that the software could be very slow, even if – and possibly because – it is supported by many devices.

After assessing the correlational values between the technical statements, the next step was to assess the correlation between each of the technical statements and the customer requirements. There were a total of 195 correlational values to be given in this assessment. The values that were used to describe the correlations were a *zero* for no correlation, a *one* for weak correlation, a *three* for medium correlation, and a *nine* for strong correlation. An example of a strong correlation would be between the statement "amount of time saved" and the customer requirement "easy to use". If the product is not easy to use, there is a high likelihood that any possible time savings will be mitigated. An example of a medium correlation would be between the statement "number of clicks to reach the desired goal" and the customer requirement "easy to use". An increased number of clicks could make the software more difficult to use, and as such, there is a correlation between the values. On the other hand, however, a software could be so straightforward, that even if you need to click many times, it would be clear to the users where they need to click, which is why the correlation can be considered medium. An example of a weak correlation would be between the statement "amount of buttons on the user-interface" and the customer requirement "efficient". Efficiency means different things to different users, and it is by no means apparent that the complexity of a software either increases or decreases the efficiency of the software. On the other hand, one could still make the case between the amount of clicks and efficiency, so a weak correlation is a fair assessment. Finally, an example of no correlation would be between the statement "amount of buttons on the user-interface" and the customer requirement "reliable". There is no simple case to be made between these two factors. The reliability seems to be completely independent of the amount of buttons on the user-interface.

After the matrix was completed, and all the correlations were assessed, the numerical values were calculated as percentages of the total, so that their importance could be assessed. The customer requirement values came from the online questionnaire, as described in chapter 3.4.2, and the importance was assessed as a percentage of the total. For instance, on a scale of *one to five*, customers appreciated efficiency as 4.67, which was 8.44% of the total points given by the customers. The percentage value is the relative importance of the customer requirement in relation to the other requirements. The technical statement values were a product of the apparent correlation values in relation to the customer requirements. As the statement "amount of time saved" was positively correlated to many of the customer requirements – in other words, receiving many *nines* – the total importance of the said statement ended up being 15.34%. When one compares this to the least important technical statement "amount of different possible filtering combinations available to the user", receiving only 2.67% of the correlation points, it can be easily understood what are the more crucial technical statements when planning the product. The QFD planning sheet is found in appendix III.

3.4.2.3 QFD Conclusions

The target of the QFD analysis was two-fold. On one hand, the idea was to test the concept by finding consistencies or inconsistencies with the data gathered from the literature review and the interviews. On another hand, the target was to provide as comprehensive foundation as possible for the prototype, so that any part of the prototype can be further utilized in future research or development. Figure 25 shows all the technical statements and their relative importance.

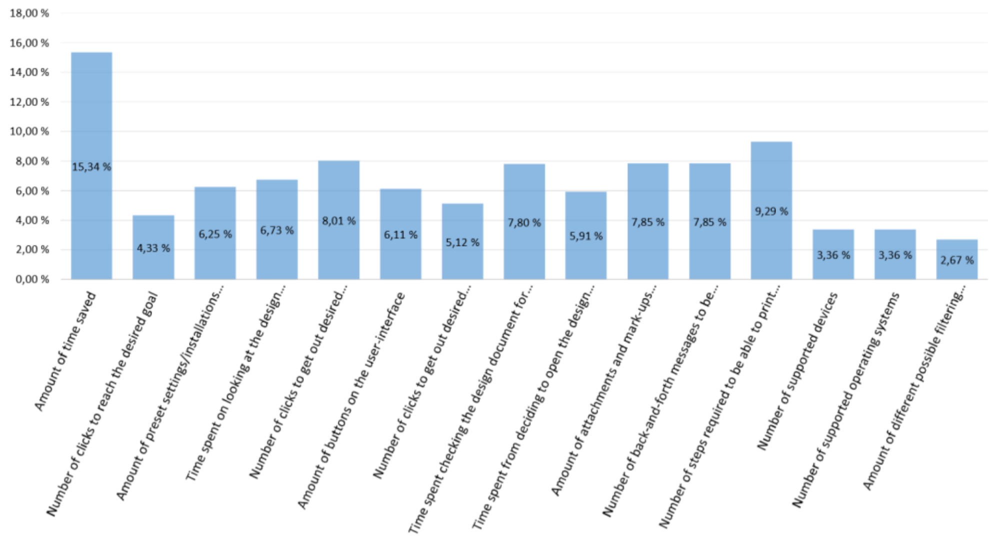

Figure 25: Technical Statements of the QFD Analysis and Their Relative Importance

The data from the QFD can be analyzed in a number of ways, but one interesting finding is that different aspects seem more valuable when assessed in this manner. The amount of saved time, to give an example, was not an explicit discussion but in rare cases, although the conversations did circle around topics such as project deadlines, worry over the lack of efficiency, and so on. Yet, when assessing the technical statement "amount of time saved" in relation to the customer requirements, it seems to be the most central of the statements. Similarly, the technical statement "amount of different possible filtering combinations available to the user" could be seen as a relatively important aspect, as it was mentioned rather explicitly by several of the interviewees, yet when assessing the importance of the technical statement in relation to the customer requirements, its relative importance is the lowest among the proposed technical statements. Thus, assessing the interview findings in unison with the QFD results can be a powerful tool for assessing and arguing what elements of the prototype truly need to be taken further, and at what cost.

The technical statements were derived from the customer requirements, which were in turn derived from the interview data. Thus, connecting the technical statements to the themes found during the data analysis may shed us some light onto whether the technical statements represent the themes properly. Figure 26 is an illustration of which technical statements belong under which themes. Two of the technical statements can be categorized under *realities & restrictions,* four of them can be categorized under *data,* four under *platform,* and five under *collaboration.* The overall representation of all the themes among the technical statements is divided rather equally, even more so if they are assessed on the basis of their relative importance. *Realities & restrictions* –theme represents 21.25% of the correlation points, *Data* represents 21.53% of the points, *Platform* represents 19.08% of the points, and *Collaboration* represents 38.12% of the points.

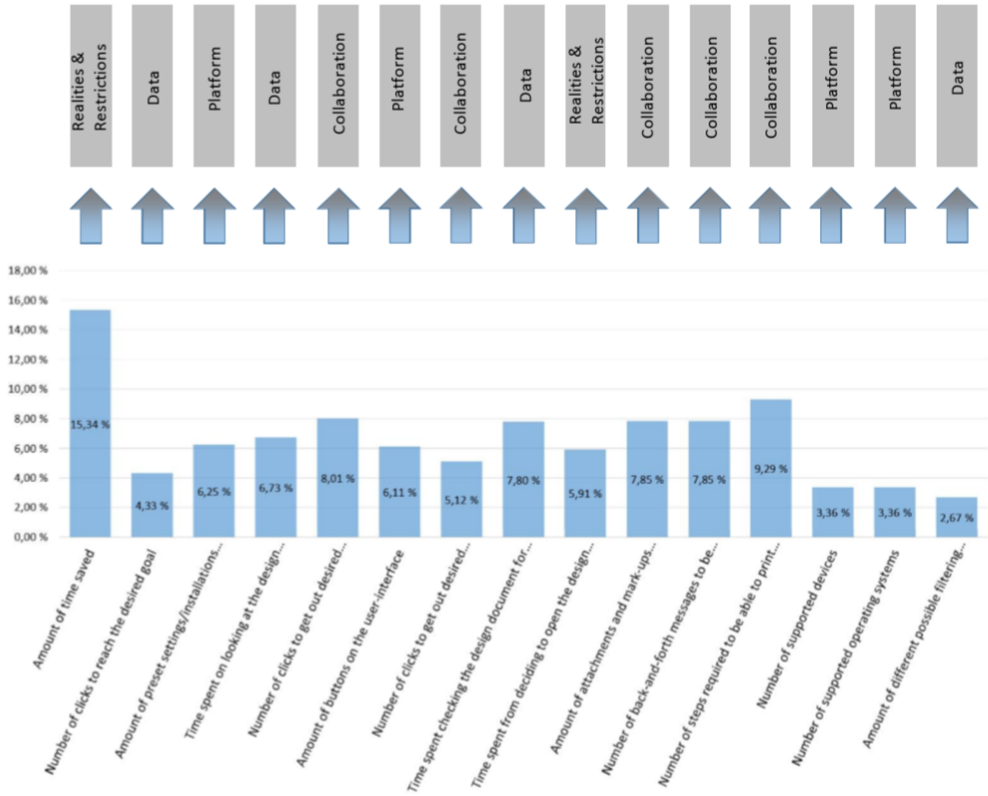

Figure 26: Technical Statements Placed Into the Four Themes of the Interviews

According to Haag et al. [58], QFD improves user involvement, manager support and involvement, and project development. It also shortens software development life cycle, functions as a structured methodology, supports team involvement, and helps to avoid loss of information, to mention but a few. Furthermore, in comparison to traditional methods, it improves communication between all the relevant parties and helps to meet customer requirements. Alrabghi [59] also points out that the nonfunctional requirements – such as “easy to use” – are often disregarded, which negatively affects the quality of the final product. Utilizing QFD helps developers and engineers to not overlook the value of nonfunctional requirements. According to Alrabghi [59], QFD can also be used to conduct customer competitive assessments. In the case of this study, however, no comparable solutions are in the market yet, and as such, no competitor analysis was conducted. The sheet in Appendix II, however, can be later continued by introducing a competitor analysis.

3.4.2.4 QFD Sheet Utilization

As was mentioned in chapter 3.4.2, one of the targets of the QFD analysis was to provide as comprehensive foundation as possible for the prototype, so that any part of the prototype can be further utilized in future research or development. While this research is limited in scope, so that the QFD findings are not utilized to further develop the technology, the QFD findings can and hopefully will be used to further develop the technology or parts of the technology suggested in the prototype.

One of the values of the sheet is that it can be used in the future by re-evaluating the suggestions provided in the QFD sheets. Updating or crystallizing the customer requirements and technical statements can be done easily, and furthermore, introducing competitor analysis to the QFD sheet is easy when most of the work has been done already. According to Alrabghi [59], updating the requirements can be a beneficial exercise, as the customer voice is a continually evolving source of insight, as trends and challenges shift in the industry. Another beneficial use-case for the QFD sheet is to apply it to practice as it is. One can already take a customer requirement or a technical statement, and inspect its effect on other customer requirements and technical statements, and they can further study the relative importance of each of the attributes.

4 DISCUSSION

In this thesis, I studied the possibilities on how to attain a paradigm shift in the field of drawing consumption by using two different approaches. A theoretical research, where I focused on answering the four research questions presented in chapter 1.2.1., and a proof-of-concept study introduced in chapter 1.2.2, where I tested the findings of the theoretical research by concretizing the findings and taking the prototype to the clients for feedback. The proof-of-concept study produced a prototype that can be utilized in future research and development. Screenshots of the prototype can be found in Appendix IV. The four research questions were:

> *"Where is the industry at the moment regarding engineering drawings, and what – if any – are the most promising ideas emerging from the research that may provide new means to challenge the current paradigm of drawing consumption?"*

> *"What are the underlying forces, the needs and the requirements that are manifested in engineering drawings universally?"*

> *"What are the ways in which engineering drawings are or can be used – besides the explicit ways – that can provide additional value to anyone or anything involved in the process of consuming drawings?"*

> *"What are the critical elements – both, positive and negative – that constitute a successful diffusion process of a new technology?"*

The first research questions effectively pointed us to the direction of technologies that may have a role in bringing about a paradigm shift in the field of drawing consumption. These findings were amalgamated into the prototype concept, and were generally well accepted by the interviewees as solutions of the future. The suggested technologies or ideas that will most likely play a part in the paradigm shift are *Mixed Reality & Virtual Reality, Drawingless & Paperless Engineering, Internet of Things & Industrial Internet, Artificial Intelligence & Machine Learning, Cloud Computing, Big Data,* and *Building Information Modeling.*

The findings do suggest that one reason a paradigm shift has not been attained is indeed the lack of a suitable technology. All the interviewees suspected that paper cannot be replaced by current technologies simply because any tablet computer or a cellphone currently in the market do not function reliably in bad weather conditions, for example, during a rain. On the other hand, some of the interviewees were hopeful that such technologies may exist already – or are under development – and that they will replace paper eventually. The technologies or ideas were not addressed one by one during the interviews, as it was in no way assumed during the study that the listed technologies or ideas are an exhaustive list of solutions that will be part of the solution. Rather, they were an outline of possible technologies or ideas that could be used to argue the validity of the prototype, and further, to have some points of references to reality during the interviews instead of conducting the discussions in full abstraction.

The second research question provided a rich understanding of what drawings are made of, and why is it that certain ways of consuming and creating drawings have been traditionally followed. These findings helped me to understand which parts of drawings are necessary in and of themselves, and which parts are simply there due to format restrictions, or the like. One example of a drawing element that is purely placed due to format restrictions would be location figures. If we had, for example, a 3D model with accurate coordinates, we would not need a miniature map of the project site printed on the side of the paper drawing. Utilizing coordinates, however, used to be time consuming before the time of 3D models, and although inaccurate, a map on the side of the drawing delivers the necessary amount of information with a precision that is acceptable to the final consumer of the drawing. While during this study I did not break down every possible element that exists due to a format requirement, a valid argument can be made that if a paradigm shift is something desirable in the field of drawing consumption, we cannot assume that it would be attained simply by transforming existing documents into a 3D display of themselves. This is in no way a minor claim, as it was pointed out that engineering drawings – unlike artistic drawings – are documents that do not deliver only information, but also the legal liability of the correct interpretation of the drawing to the consumer of the drawing. Hence, any changes to the collectively agreed upon ways of working need to be addressed using utmost care, as the current paradigm has been developed and refined over long stretches of time.

As quantity surveyors were introduced as a separate group with specific needs regarding drawings, an argument can be made that even if one user group agrees that some elements in drawings are not required in the given form anymore – or perhaps they exist only due to the format restrictions – another user group could find the said elements absolutely vital to their work. A good example would be the contrasting user cases between builders and quantity surveyors, who could be consuming the same set of drawings for different information. Drawings are not a mere end-product of a design solution, but rather a dynamic document that offers different information to different user groups, while also being a legal document that binds different user groups together by enforcing a common language through the unambiguous nature of the drawing. These findings are strongly backed up by the interview findings introduced in chapter 3.1.4, where we introduced the four themes – which, at minimum, are quasi emergent properties of the interview data. The themes display qualities of drawings that seem to divide a drawing document at least into four different categories of discussion. The four quasi emergent themes of drawings are *data*, *platform*, *collaboration*, and *realities & restrictions*. The themes represent different qualities of drawings that all have to be taken into account when addressing the paradigm. For example, one cannot simply focus on improving the quality of data, if one does not understand how the users utilize drawings in communication. Thus, we can make a case that *data* as a theme, and *collaboration* as a theme do not exist independently from each other, but rather, the themes form the corpus of the current paradigm of drawing consumption.

The third research question helped me to understand drawing contents, as there are more to drawings than what meets the eye. One of the important findings was noninformation, which, I suggested, is information that is informative precisely because of its apparent absence. I made a case for the existence of noninformation, as it seems to be absolutely clear that data is more informative when it is combined with other data. Two examples of noninformation were given in chapter 2.2.3. The basic idea is that, as data is presented on a drawing, the placement of data in relation to the geometry or other units of data helps the consumer of the drawing in extracting proper information out of the drawing. The inclusion of noninformation is necessary, as was further pointed out in chapter 2.2.3, due to the conflicting requirements of drawings as a document. On one hand, drawings are supposed to have as little repetitive detail and hidden lines as possible, and on the other hand, drawings are supposed to be constructed in a manner that makes them unambiguous – something that inherently increases repetitive detail and hidden lines.

Drawings are not only used as contractual documents, or as informative documents for the purposes of building or quantity take-off. They are also used to think, to talk, to communicate, to represent, and to store. The importance of these user cases cannot be over-estimated, if one wants to understand how to go about changing the paradigm of drawing consumption. Drawings, for example, are a convenient platform to share information during a meeting. Two people may have an argument about the placing of a column that does not exist yet. On one hand, the common a priori position that 3D models will inevitably replace traditional drawings is a tempting position to hold. On the other hand, however, the interviewees worried that 3D models are not as accessible as drawing documents. Models are slow to open, they require special software to function, the special software need complex login procedures, and one has to have a filter or coordinates to find the place he or she wants to show during a meeting. As such, the usability of drawings in a meeting environment, or the like, is easily superior to 3D models of today. Two of the interviewees suggested that if drawing data was consumed in a 3D model, the users would have to be able to access their data of choice as easily as by opening a PDF document – no logins required, virtually any computer has a PDF reader, and the format is so accessible that they know they can share the information forward, too.

The fourth research question was an attempt to help me understand how a prototype would have to be made, so that it would have any chances of actually raising interest in the ideas presented in the prototype. The focus was on the diffusion of technology. The prototype was created based on the findings of chapter 2.2.4, meaning that the introduced five perceived attributes *relative advantage, compatibility, complexity, trialability,* and *observability* were taken into account when creating the prototype. Relative advantage, in the case of this prototype, meant that the prototype would be able to solve more problems regarding drawings than the current solutions in the market. Compatibility was addressed by borrowing the user interface of a software that all the interviewees were familiar with. This way, the interviewees did not have to spend time trying to understand the suggestions from the scratch. Complexity was addressed by not trying to explain all the technical background requirements for the technology, but showing them a user case, for example, of how to print a drawing with the prototype. Trialability was addressed by making most of the prototype clickable. This way the interviewees could actually see where they have to click, which in turn would create a sense of them actually trying a ready software. Finally, observability was addressed by including animations and screenshots into the prototype. Some complex features were not made into clickable prototypes, in which case the user could at least observe how the software functions instead of receiving mere explanations of how it should work. Furthermore, the interviewees in question were recognized as either feeders or insiders of Tekla Structures, as would be categorized by the identity magnet introduced in chapter 2.2.4, and as such, their legitimacy was taken into account during the development of the prototype. The fourth research question was mainly utilized in the research to have some foundation on what needed to be taken into account when creating the prototype. Having a prototype that is diffusible into the interviewee group was important, as the ideas presented in the prototype were complex. Even if the ideas would have been good in and of themselves, the interviewees could have rejected them completely if all of their energy would have been used to try to understand the underlying technology.

Based on the theoretical findings of the research questions, a set of interviews were conducted to test and to confirm the theoretical findings. The interview data were then analyzed, and the important findings were amalgamated into a prototype suggestion, which was an attempt to introduce a technology that could bring about a paradigm shift in the field of drawing consumption. The prototype was then tested for validity by conducting a second round of interviews. According to the interview data of the second round of interviews, the interviewees considered the prototype a step to the correct direction in moving away from traditional drawings toward something that could be considered a paradigm shift. There were, however, some worries and some future suggestions for the prototype, as well. The answers are analyzed in detail in chapter 3.4.1. After the interview data were analyzed, a quality function deployment analysis was conducted on the prototype. The QFD findings enrich and diversify the findings of the interviews. For instance, "the amount of time saved" as a technical measure was something that was not an explicit topic in the interviews, but was clearly important when mirrored to the customer requirements during the QFD analysis.

While a lot of work remains in order to attain a paradigm shift in the field of drawing consumption, this thesis has articulated many implicit ideas and practices that need to be taken into account in the pursuit of the said goal. Furthermore, through the prototype, this thesis provides a suggestion on how to move toward the paradigm shift. As Thomas Kuhn [6] pointed out in his book: "*No theory ever solves all the puzzles with which it is confronted at a given time, nor are the solutions already achieved often perfect.*"

4.1 Evaluation of the Study

As Barriball & While point out [48], a thorough interviewer training would be required when conducting semi-structured interviews. One of the main targets of an interviewer training would be to develop an awareness of personal biases or possible errors that the interviewer is susceptible to given his personal interview technique. Such trainings were not undertaken by the interviewer, although some interviewing experience has been included in the studies preceding this thesis that partially fulfill the degree requirements in question.

The interviews were conducted in Finland, and the geographical location or culture could have had an effect on some of the quotations presented by the interviewees. On the other hand, the interviewees often elaborated the answers by pointing out that some aspects of their answers were likely to be influenced by their cultural particularities. For example, Interviewee A pointed out that the building authority in Finland would rather likely be open to ideas that would make drawing consumption more digital. Then, he further pointed out that this would not necessarily be the case in countries with more conservative building authorities.

The interviews were conducted using a set of pre-planned interview questions, but the actual interviews did contain discussion that were not among the pre-planned questions. On one hand, this allowed to mitigate the possible negative effects of the lack of experience of the interviewer, allowing important topics to be discussed that were unforeseen prior to the interviews. On the other hand, every interview was more different than perhaps would be allowed for a properly arranged semi-structured interview. These notions can be accounted for the limited experience of the interviewer.

The scope of the research turned out to be bigger than was initially expected when the research questions were formulated. Due to this, some of the topics or research questions are not handled as widely as perhaps would have been necessary to provide even more accurate research findings. Furthermore, there were so many valid points of feedback during the second round of interviews that the prototype would require more rounds of iteration to fully capture all the important ideas that emerged during the interviews. Then again, for the purposes of this research, two rounds of interviews sufficed in testing the concept for validity, and providing a foundation for future research or development.

When conducting the QFD analysis, the selected customer requirements were not exhaustive in any sense. The customer requirements were derived from the interview data, but more input would be needed to capture all the possible customer requirements. They were enough to test the concept and the findings of this study, but if the prototype was developed further, a more thorough customer requirement analysis would have to be conducted.

4.2 Future Research and Development

All of the research questions were interesting and valid for the intellectual and philosophical question at hand. No research question was answered exhaustively, however. The findings provided in this thesis are a good contribution to the body of knowledge of each of the question, but further studies are needed. Each research question could be extended to a separate study that would yield interesting results. The themes that were found during the interviews can be utilized as a basis for identifying drawing characteristics in future research and development, for they prove that drawings are not simply an end product on paper, but have at least four separate themes that need addressing when the qualities of drawings are being studied.

The prototype that was produced during the study can be used primarily by the funding organization for future research and development. As this thesis is public, however, the ideas are open and available for anyone. Some documentation, such as the coded interview findings, and the actual prototype, are not available to other parties than the funding organization, however. Prototype screenshots can be found in Appendix IV.

The QFD sheet, found in appendix III, is a good basis for future development of the prototype. It provides a foundation of a more thorough QFD process that could, for instance, include competitor analysis, among others. The QFD sheet can be accessed by anyone, and provides a good basis for similar development tasks. Although the average values for customer requirements can be found in the QFD sheet in Appendix III, the detailed data provided by the customers can only be accessed by the funding organization.

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APPENDIX I

Interview Questions of the First Round of Interviews.

- If we think about a project that is starting, or maybe a new phase in an existing project, at what point drawings are introduced to the tasks?
- From where or from who do you get those drawings?
- How are the drawings physically delivered to you specifically?
- In what different formats do you get drawings?
- Are they perhaps printed always, or in an electronic format, or something else?
- What different purposes do you use drawings for?
- What different information you get from these different purposes?
- Do you ever face a situation that the drawings do not meet your needs? For example, if there are mistakes?
- If yes, what kind of process is initiated when you face this situation?
- If yes, how do you continue working?
- Do you ever face a situation that you don't understand something in the drawing? Either due to a lack of your expertise, or perhaps because the drawing is made badly?
- If yes, what process is initiated when you face this situation?
- Do you need to use drawings during meetings?
- How is the communication conducted in such situations?
- Do you need to place orders on the basis of drawing information?
- If yes, what kind of process is that?
- Besides meetings, do you need to arrange discussions about drawings with other people?
- Do you ever need to make notes or markings on drawings?
- How do you do that?
- What kind of process is followed after that?
- Have you ever faced a situation where you have built something differently than what was shown on a drawing? Or if you are the creator of the drawing, have you ever faced a situation where someone has built something differently than what you showed on a drawing?
- If yes, what kind of process was initiated after that?
- How important is the professionalism of the person reading the drawing?

- Is there ever a need for more detailed instructions on a drawing, besides the drawing itself. For instance, additional textual or other input?
- Are drawings ever presented so ambiguously that there is room for interpretation in the consumer end of the drawing?
- What kind of requirements are there for the person who is reading the drawing?
- Have you ever faced a situation, where a drawing was clearly wrong, and perhaps the outcome would be dangerous if the builder would follow the instructions?
- If yes, what kind of process was initiated after that?
- In what other ways the different parties of a construction project communicate, besides drawings, when they are discussing matters that are mostly communicated using drawings?
- What other relevant user groups drawings have besides engineers, designers, architects (and other parties who create drawings) and the construction site (on-site managers, workers, and so on)?
- What other design documents do you use besides physical papers or PDFs?
- Can you tell about the benefits of these other design documents in contrast to paper or PDF?
- Do these other design documents replace paper or PDF in some sense?
- Do they only provide extra value, or do they actually replace something that would be transmitted via paper or PDF otherwise?
- What is the feedback mechanism, if drawings are faulty or something is missing?
- Do the creator of the drawings go to check how their drawings have been utilized in practice?
- Do you or does someone need to document how things have been built on-site? How?
- Does the format of the drawing ever pose any difficulties to the user?
- Is paper ever a restriction in presenting something?
- Besides paper, what devices you use to consume drawings?
- What is the advantage or disadvantage of presenting the general text on drawings on the side of the paper?
- Is there some information that is often missing in drawings?
- Are there any cultural factors in the communication process regarding drawings?
- For instance, do you need to always talk to certain superiors or certain people, instead of the most convenient person?

- What do you see as the biggest challenge regarding drawings today?
- Do you think 3D environment could replace traditional drawings one day? Why or why not?
- Is there some benefit to traditional drawings that 3D cannot simply replace?

APPENDIX II

Online questionnaire for mapping out the customer requirements.

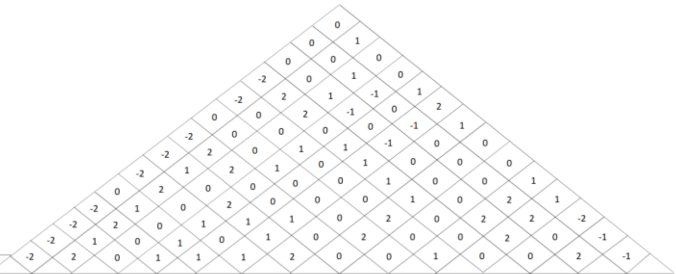
How important the following factors are in the presented prototype? (From 1…5)

1. Efficiency
2. Ease of use
3. Ease of access to design documents
4. Visual clarity
5. Ease of adding one's own annotations
6. Ease of exporting data
7. Reliability
8. Quickness
9. Ease of communication
10. Ease of printing design documents
11. Availability for different devices and platforms
12. Possibility to read sequenced data
13. Possibility to filter existing design documents according to one's own wishes

14. Do you want to clarify some answer? (Free textual input)

APPENDIX III

Quality Function Deployment –Sheet



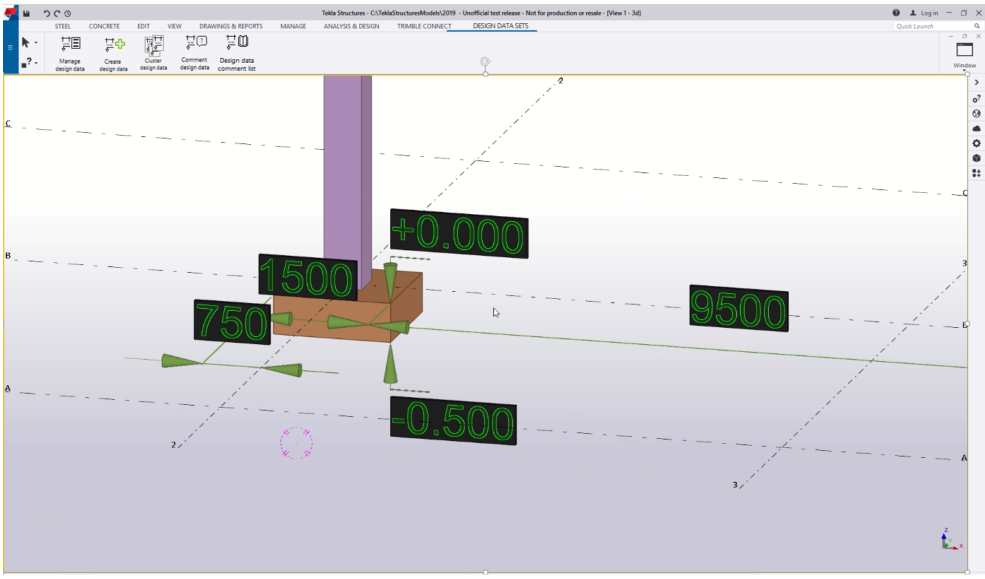
Customer requirements	Importance (1-5)	Importance (%)	Technical Measures	Amount of time saved	Number of clicks to reach the desired goal	Amount of preset settings/installations required to be able to open a design document	Time spent on looking at the design document to understand the content	Number of clicks to get out desired measurement data	Amount of buttons on the user-interface	Number of clicks to get out desired object/assembly level data	Time spent checking the design document for errors	Time spent from deciding to open the design document until having it open	Amount of attachments and mark-ups needed to transmit the desired message	Number of back-and-forth messages to be able to explain a situation	Number of steps required to be able to print what is on 3D	Number of supported devices	Number of supported operating systems	Amount of different possible filtering combinations available to the user
			U / N / D	⇧	⇩	⇩	⇩	⇩	▭	⇩	⇩	⇩	⇩	⇩	⇩	⇧	⇧	⇧
Efficient	4,67	8,44 %		9	3	3	3	3	1	3	9	3	3	3	3	1	1	0
Easy to use	4	7,23 %		9	3	9	9	3	9	3	3	1	1	1	3	0	0	1
Easy to access	4,33	7,82 %		9	1	9	0	9	3	1	0	9	0	0	3	0	0	0
Visually easy to understand	3,67	6,63 %		9	0	0	9	0	0	0	3	0	3	3	0	0	0	1
Easy to add your own dimensions	5	9,03 %		9	3	0	1	9	1	0	3	0	9	9	3	3	3	0
Easy to extract desired data	4,67	8,44 %		9	3	1	3	9	1	9	3	0	3	3	9	1	1	3
Reliable	4,67	8,44 %		9	0	0	1	0	0	0	3	0	3	3	0	1	1	0
Fast to use	4,67	8,44 %		9	9	9	1	9	9	9	9	9	3	3	9	0	0	1
Easy to use for communication	3,67	6,63 %		9	1	3	9	3	3	3	3	3	9	9	9	1	1	0
Easy to print	4,67	8,44 %		9	0	1	0	1	1	1	0	3	0	0	9	0	0	0
Possible to use on different devices	4,33	7,82 %		3	0	0	0	0	1	0	3	9	1	1	0	9	9	1
Possibility to read sequenced data	3,33	6,02 %		3	1	3	9	0	3	0	9	0	9	9	3	3	3	3
Possibility to further filter out things	3,67	6,63 %		1	3	3	3	3	9	3	3	0	9	9	9	3	3	9
		100,00 %	Imp.	764	216	311	335	399	304	255	389	294	391	391	463	167	167	133
			%imp.	15,34 %	4,33 %	6,25 %	6,73 %	8,01 %	6,11 %	5,12 %	7,80 %	5,91 %	7,85 %	7,85 %	9,29 %	3,36 %	3,36 %	2,67 %

Correlation (-2...2)

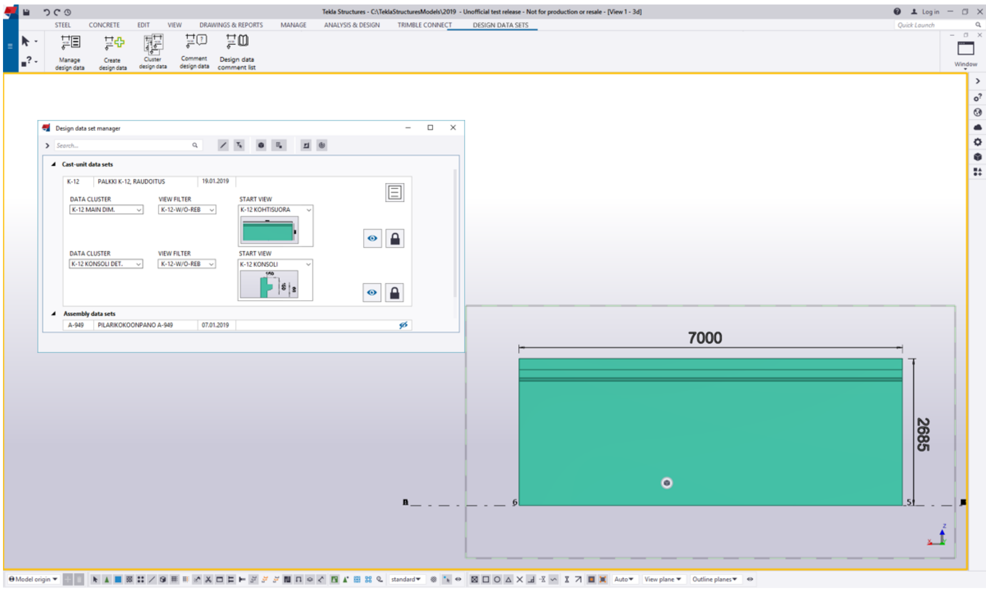
Correlation (0, 1, 3, 9)

APPENDIX IV

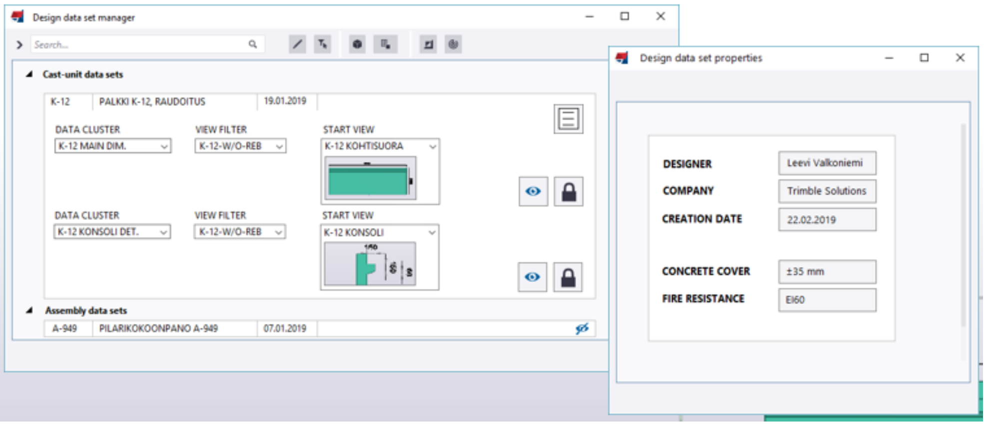
Prototype Screenshots



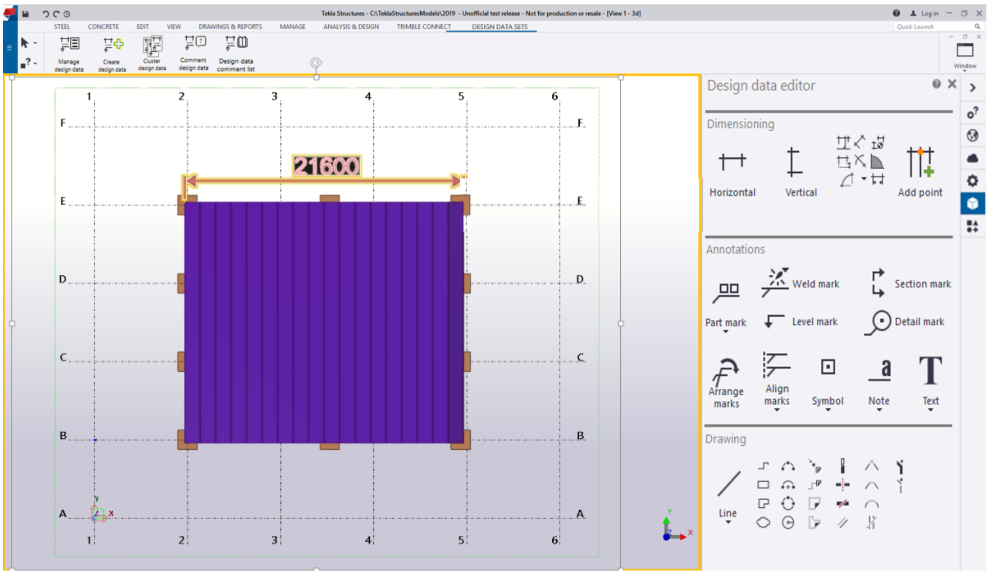
Dimensions in 3D View



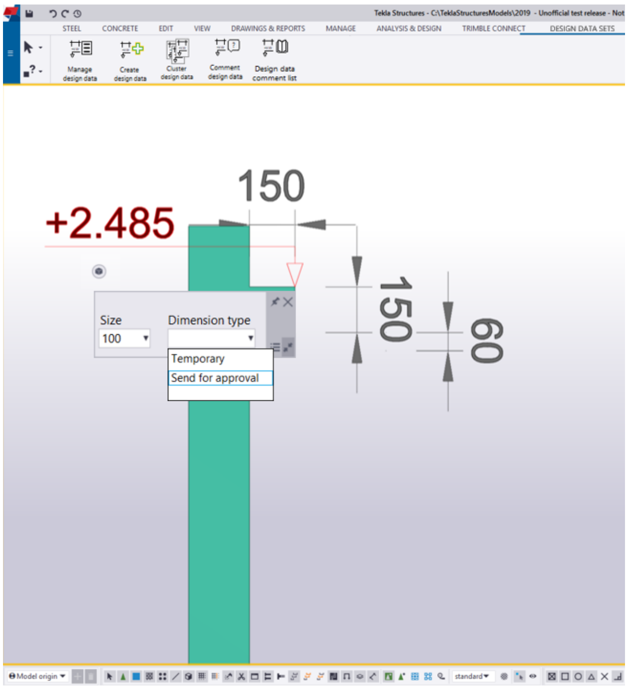
Design Data Set and Corresponding Dimensions in 3D



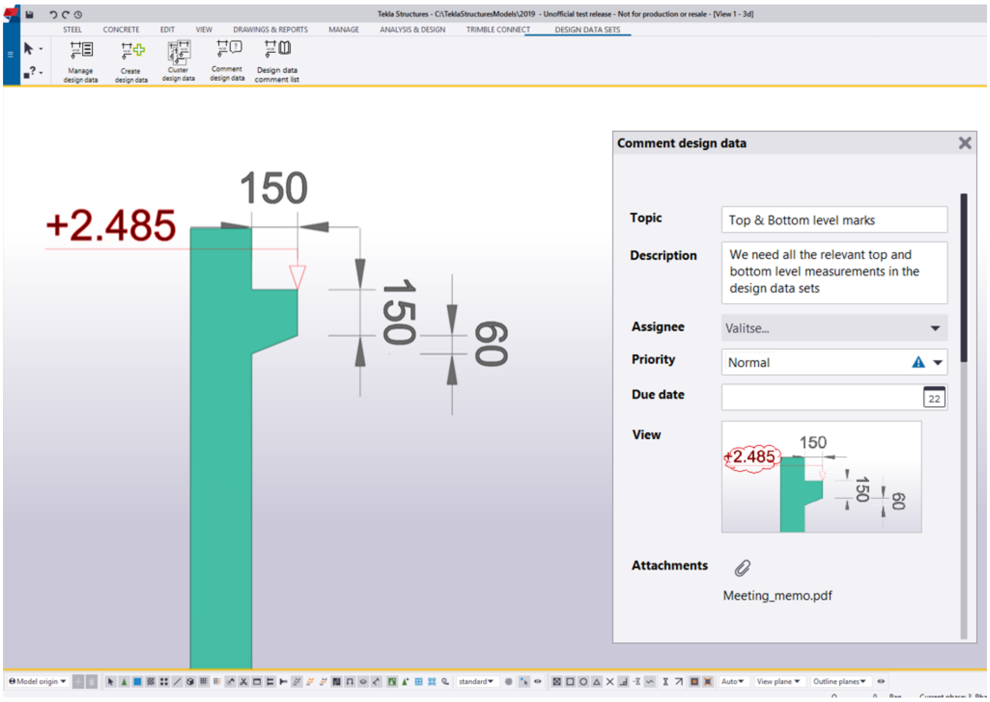
Design Data Set Manager and Design Data Set Properties



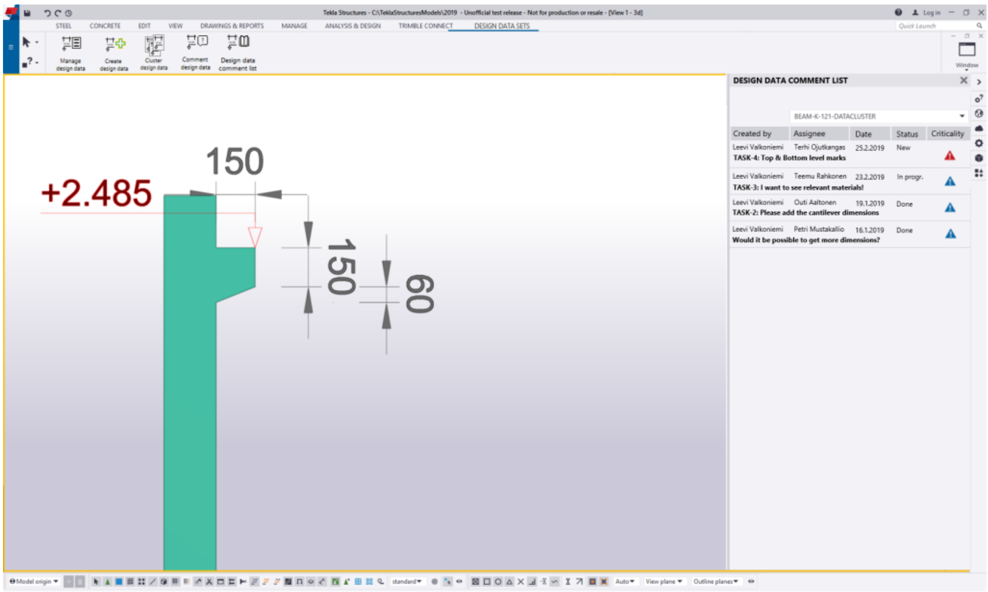
Adding Design Data Directly to the 3D View



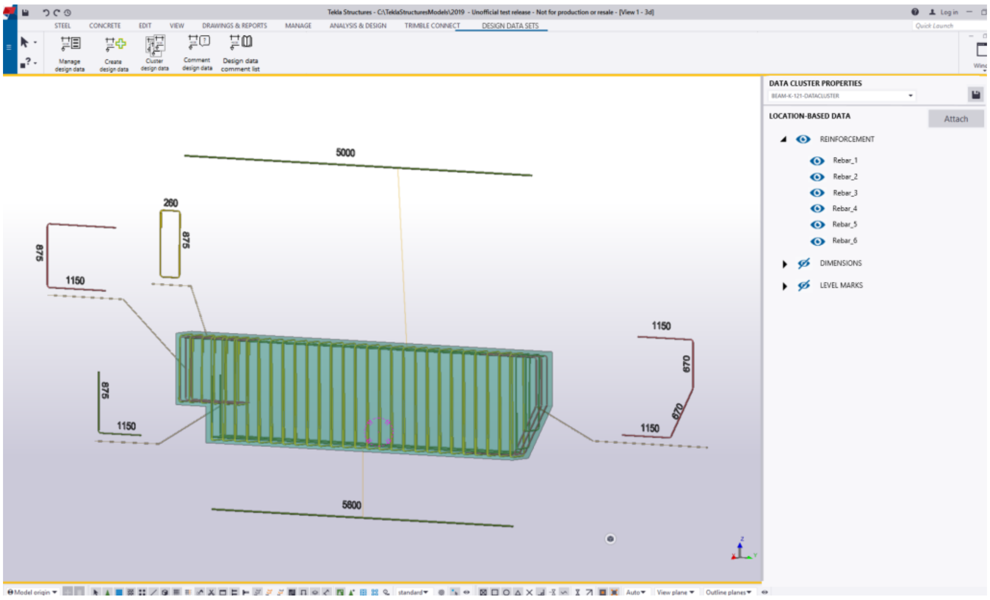
Temporary Annotations in Red Color



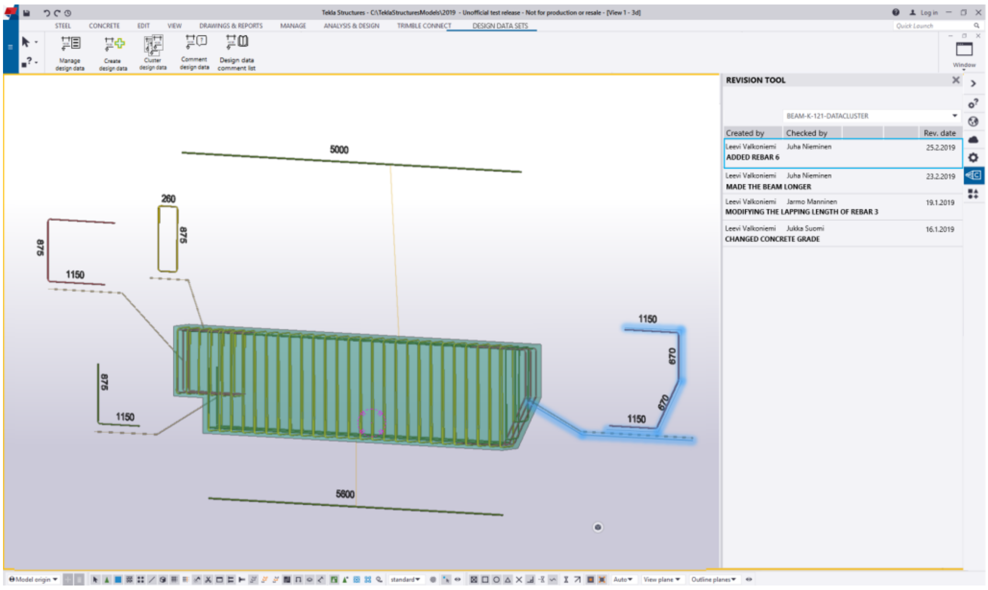
Commenting Design Data



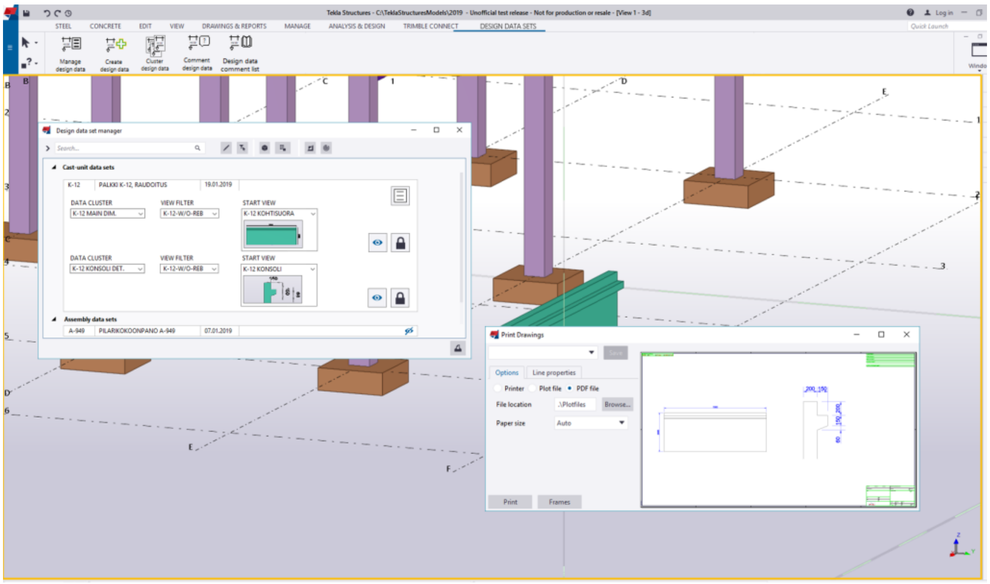
Design Data Comment List



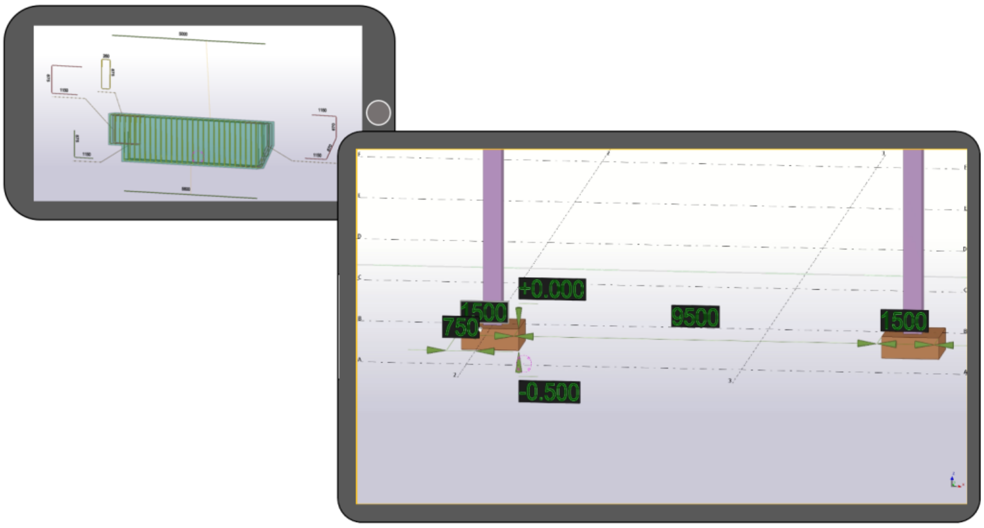
Data-Cluster Content



Change Management Tool



Printing Design Data Sets



Different Platforms